TSBF Institute

Project PE-2:
Integrated Soil Fertility Management in the Tropics

ANNUAL REPORT 2005

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

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INTEGRATED SOIL FERTILITY MANAGEMENT IN THE TROPICS

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1. TSBF-CIAT RESEARCH FOR DEVELOPMENT STRATEGY

A. Research for development strategy of TSBF-CIAT

The 2005-2010 TSBF-CIAT strategy is aligned with the **Millennium Development goal:** "to help create an expanded vision of development that vigorously promotes human development as the key to sustaining social and economic progress in all countries, and recognizes the importance of creating a global partnership for development." The strategy encompasses the **CGIAR's agriculture and environment mission:** "to contribute to food security and poverty alleviation in developing countries through research, partnerships, capacity building and policy support, promoting sustainable agricultural development based on environmental sound management of natural resources." The strategy is also aligned with the CIAT's three research for development challenges: 1) improving management of agroecosystems in the tropics; 2) rural innovation research; and 3) enhancing and sharing the benefits of agrobiodiversity.
TSBF-CIAT's Program has three main goals. These are: (1) to strengthen national and international capacity to manage tropical ecosystems sustainably for human well-being, with a particular focus on soil, biodiversity and primary production; (2) to reduce hunger and poverty in the tropical areas of Africa and Latin America through scientific research leading to new technology and knowledge; and (3) to ensure environmental sustainability through research on the biology and fertility of tropical soils, targeted interventions, building scientific capability and contributions to policy.

TSBF-CIAT utilizes a range of approaches to achieve program goals in collaboration with its partners, with particular emphasis on the following:

Catalysis: Ensuring that partners are kept at the forefront of conceptual and methodological advances by conducting and promoting review, synthesis and dissemination of knowledge. This is done through workshops, training courses and sabbatical and short exchange visits.

***Collaboration*:** Developing appropriate alliances with institutions across the research, educational and developmental spectrum, including linkages between institutions in the North and South.

***Facilitation*:** Coordinating actions among partners to achieve progress and success in research. This is done by providing backstopping support in the preparation, submission, implementation and publication of research projects.

Conviction: Demonstrating tangible results by taking policy makers to the fields.

***Internal and external reviews of the program*:** The Institute's activities and outputs undergo periodic critical reviews to ensure high standards and the achievement of the Institute's mission.

Since its founding in 1984, TSBF has conducted research on the role of biological and organic resources in tropical soil biology and fertility, in order to provide farmers with improved soil management practices to sustainably increase agricultural productivity. In recent years, TSBF-CIAT's research for development approach has been based on an Integrated Soil Fertility Management (ISFM) paradigm. ISFM is a holistic approach to soil fertility research that embraces the full range of driving factors and consequences of soil degradation — biological, physical, chemical, social, economic and political.

However, successful resource management and sustainable agricultural productivity need to go still further, into the realms of markets, health and policies (Figure 1). The central hypothesis is that natural resource management research will have more leverage if the apparent gaps between investment in the natural resource base and income generation can be bridged. Therefore, TSBF-CIAT's strategy proposes to take ISFM an additional step forward, by addressing the full chain of interactions from resources to production systems to markets and polices. Under the new framework, investment in soil fertility management represents a key entry point to agricultural productivity growth, and a necessary condition for obtaining positive net returns to other types of farm investments.

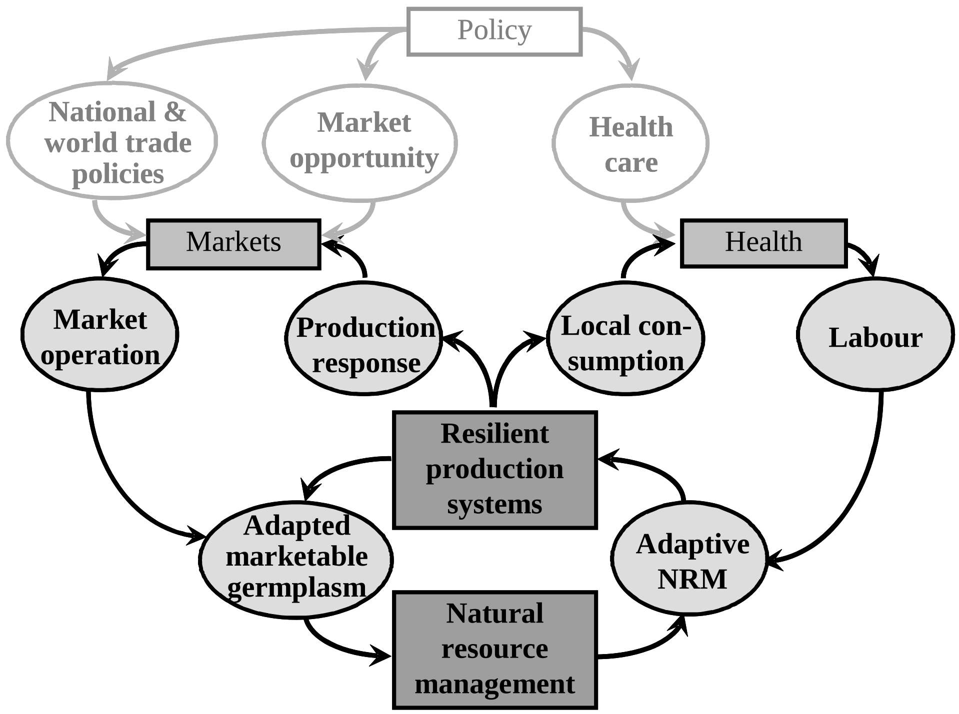

Figure 1. Conceptual framework of the TSBF-CIAT strategy. Topics in bold indicate the driving forces to be addressed by the proposed strategy; topics in shaded lighter gray are driving forces beyond the control of the Program.

TSBF-CIAT will pursue the following three major objectives under its strategy:

- to improve the livelihoods of people reliant on agriculture by developing profitable, socially-acceptable and resilient agricultural production systems based on ISFM;
- to develop sustainable land management (SLM) practices in tropical areas while reversing land degradation; and
- to build the human and social capital of all TSBF-CIAT stakeholders for research and management on the sustainable use of tropical soils.

To achieve these objectives, TSBF-CIAT's work is organized into five major outputs:

1. Biophysical and socioeconomic processes understood, principles, concepts and methods developed for protecting and improving the health and fertility of soils;
2. Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical, socio-cultural and economic processes;
3. Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils;
4. Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems;
5. Options for sustainable land management (SLM) for social profitability developed, with special emphasis on reversing land degradation.

Each of these outputs has specific output targets for each year to contribute towards output level outcomes and output level impacts. The outcomes and impacts are accomplished through six major thrusts:

1. Intensification and diversification of cropping systems;
2. Managing the genetic resources of soil for enhanced productivity and plant health;
3. Moving from plot to landscape scale to address sustainable land management challenges;
4. Understanding farm level social dynamics;
5. Linking farmers to markets; and
6. Strengthening NARSs capacity.

TSBF-CIAT's strategy has a major focus on developing and extending technologies that support sustainable intensification of cropping systems, especially in the dry and moist savanna, hillside, and forest and forest margin agro-ecological zones (AEZs) in Africa and Latin America. In these AEZs, poverty, population growth and a rising demand for food is driving expansion of cropped area into increasingly marginal lands and/or remnant forest zones. Under these circumstances, sustainable intensification of agriculture on already cultivated land represents the most promising solution to achieving food security and protecting against natural resource degradation, the ultimate goals of TSBF-CIAT's work.

As a relatively small research institute, it is important that TSBF-CIAT position itself appropriately on the research-development continuum. TSBF-CIAT's primary role and comparative advantage is in conducting international public goods research on ISFM in farming systems where soil degradation undermines local livelihoods and market opportunities. However, while TSBF-CIAT will focus primarily on strategic research, it is also ready to support technology dissemination and development activities with partners via regional networks and global projects. TSBF-CIAT will continue research on below-ground biodiversity as a means of beneficially managing soil biology, through the GEF-UNEP funded global project on below-ground biodiversity (BGBD) which has successfully completed its Phase I and is about to start its Phase II activities.

Much of the applied research and dissemination of findings, as well as NARSs capacity building, will be done via the Institute's two partner networks — the African Network for Soil Biology and Fertility (AfNet), and the Latin American Consortium on Integrated Soil Management (known by its Spanish acronym, MIS). TSBF-CIAT also collaborates with the South Asian Regional Network (SARNet) on soil fertility research in that region.

To carry out the work envisioned under the new strategy, the following staff positions will be called for:

Agrobiophysical scientists: These include specialists in integrated soil fertility management, soil biota management, soil and water conservation, ecosystem services, microbiology, and plant nutrition and physiology.

Social scientists (including agricultural economics): This staff category will be strengthened to permit greater emphasis on the socio-economic aspects of the new research paradigm.

Coordination: This includes the Institute Director, coordinators of the AfNet and MIS networks, and the coordinator of the GEF-UNEP Below Ground Biodiversity Project.

Funding: The estimated funding required for TSBF-CIAT's work is approximately US$5 million per year, for a total budget of about $25 million over the next 5 years.

B. Organization of the report

This annual report for 2005 is organized with the following sections. It starts with a brief summary of the strategy of the TSBF-CIAT followed by a brief description of the project and its logfrme that includes the 5 outputs, output targets for each output, outcomes and impacts at each output level as described in the CIAT Medium-Term Plan 2006-2008. This is followed with a section on research highlights organized according to the 5 outputs. The full report is organized by 5 major outputs of the project. Each output report contains its rationale, key research questions, milestones for the year 2005, highlights of research and specific output targets for the years 2006, 2007 and 2008. For each output target, the published work is reported as abstracts from refereed journal articles that were published in the year 2005. This is followed by the completed and on-going research activities that are related to each output target. Progress towards output level outcomes and output level impacts are summarized at the end of the report for each output. Information on list of staff, list of students, list of partners and list of publications is included in the Annexes section.

C. Project outputs and their link to strategy

The project has 5 major outputs. Output 1 (Biophysical and socioeconomic processes understood, priciples and concepts developed for protecting and improving the health and fertility of soils) involves research to develop principles and concepts that transcend the classical boundaries of the biophysical sciences and require integration with economics, sociology and anthropology. Integration of local and scientific knowledge to develop integrated "hybrid"knowledge and therefore could increase relevance to an overall strategy for sustainable soil management for improved food security and environmental protection.

Process and integrated knowledge generated from the research activities in output 1 needs to be translated into sustainable soil fertility and land management practices, adapted to the socio-cultural and economic environment in which these practices will be implemented. Research activities from Output 2 (Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical and socioeconomic processes) are expected to enhance farmers' capacity to translate best principles for soil, water and land management into practices that are appropriate to their environment and decision aids, condensing that knowledge for dissemination beyond the sites where this knowledge has been generated.

Managing soil fertility for improved livelihoods requires an approach that integrates technical, social, economic and policy issues at multiple scales. To overcome this complexity, research and extension staff need the capacity to generate and share information that will be relevant to other stakeholders working at different scales (i.e., policy makers, farmers). Thus the research activities in output 3 (Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils) are founded on building the human and social capital of all TSBF-CIAT stakeholders, research and management on the sustainable use of tropical soils.

Research activities of output 4 (Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems) address the challenge of intensification and diversification of smallholder agricultural production that is needed to meet the food and income needs of the poor and cannot occur without investment in natural resource management, especially soil fertility. Investment in improving soil fertility is not constrained by a lack of technical solutions *per se* but is more linked to lack of access to information for improved decision making and analyzing trade-offs, inputs and profitable markets.

Soils play a central role for the provision of ecosystem services such as regulation of water quality and quantity, carbon storage and control of net fluxes of greenhouse gases to the atmosphere. Appropriate soil management could result in enhanced provision of environmental services. The major objective of research activities of output 5 (Options for sustainable land management (SLM) practices for social profitability developed, with special emphasis on reversing land degradation**)** is to restore degraded agroecologies to economic and ecological productivity by generating technology, institutional and policy innovations that restore degraded agricultural lands, enhance ecosystem health and improve livelihoods.

2. PROJECT DESCRIPTION AND LOGFRAME

CIAT PROJECT PE-2: INTEGRATED SOIL FERTILITY MANAGEMENT IN THE TROPICS

Project Description

Goal: To strengthen national and international **capacity** to manage tropical ecosystems sustainably for human well-being, with a particular focus on soil, biodiversity and primary production; to reduce **hunger and poverty** in the tropical areas of Africa and Latin America through scientific research leading to new technology and knowledge; and to ensure **environmental sustainability** through research on the biology and fertility of tropical soils, targeted interventions, building scientific capability and contributions to policy.

Objective: To support the livelihoods of people reliant on agriculture by developing profitable, socially-just and resilient agricultural **production systems** based on Integrated Soil Fertility Management (ISFM); to develop **Sustainable Land Management** (SLM) in tropical areas of Africa and Latin America through reversing land degradation; and to build the **human and social capital** of all TSBF-CIAT stakeholders for research and management on the sustainable use of tropical soils.

External Conditions: Security and political stability does not restrict access to target sites and continuation of on-going activities.

Important Assumptions: Poverty reduction strategies remain central to human development support and funding. TSBF stakeholders remain engaged with TSBF-CIAT strategic priorities and/or TSBF management continues to adapt and innovate in response to changing priorities.
Funding for research on globally-important issues continues.

Target Ecoregions: East and Central African highlands (Kenya, Uganda, Ethiopia, Tanzania, Rwanda, DR Congo); Southern African savannas (Zimbabwe, Malawi, Mozambique, Zambia); West African region (Burkina Faso, Niger, Cote d'Ivoire, Nigeria, Benin, Togo, Mali, Senegal, Ghana); Central American hillsides (Honduras, Nicaragua); Andean hillsides (Colombia, Ecuador, Peru; Bolivia); Tropical savannas of south America (Colombia, Venezuela); Amazon rainforest (Brazil, Colombia, Peru).

Beneficiaries and End Users: Principally small-scale crop-livestock farmers and extension workers, NGO's and NARES in tropical agroecosystems of sub-Saharan Africa, Latin America and South-east Asia.

Collaborators: ***NARES:*** KARI (Kenya), DRSRS (Kenya), NMK (Kenya), KEFRI (Kenya), NARO (Uganda), NFA (Uganda), NEMA (Uganda), MOA (Uganda), ITRA (Togo), INRAB (Benin), SRI (Ghana), IER (Mali), IAR (Nigeria), INRAN (Niger), INERA (Burkina Faso); CORPOICA (Colombia), EMBRAPA (Brazil), Kerala Forest Research Institute (India), GBP Institute (India), SDREP (India), INTA (Nicaragua), DICTA (Honduras); IC-SEA BIOTROP (Indonesia), RIABGR (Indonesia), FNCRDC (Indonesia), FNCRDC (Indonesia), RRIEC (Indonesia), COSA (Indonesia), IOS (Cote d'Ivoire), ANADER (Cote d'Ivoire), NRMEE (Cote d'Ivoire), MOE (Cote d'Ivoire), INPDMDS (Cote d'Ivoire), ESDA (Cote d'Ivoire), UCA (Cote d'Ivoire), UAA (Cote d'Ivoire), BNETD/CCT (Cote d'Ivoire), CNRA (Cote d'Ivoire), (Instituto de Ecologia (Mexico), IEAC (Mexico), UNAM (Mexico), IFCP (Mexico), Centro Exp. Andres (Mexico), Reserve de la Biosfera de Los Tuxtlas (Mexico), ***ARIs:*** CIMMYT, ILRI, CIP, IFDC, ICRAF, IITA, ICRISAT, IRD (France), CIRAD (France), ETHZ (Switzerland), JIRCAS (Japan); ***Universities:*** Nacional (Colombia), UNA (Nicaragua), UNA and EAP Zamorano (Honduras), Uberlandia (Brasil), University of Nairobi (Kenya), USIU (Kenya) Maseno University (Kenya), Methodist University (Kenya), Makerere University (Uganda), Kenyatta University (Kenya), Zimbabwe (Zimbabwe), Sokoine (Tanzania), Universidade Federal de Lavras (Brazil), Universidade Regionale de Lavras-FURB (Brasil), INPA (Brasil), UFAM (Brasil), Universidade De Brasilia (Brasil), Jawaharlal Nehru University (India), University of Agricultural Sciences (India), Kumaon University (India), Sambalpur University (India), Universitas Lampung (Indonesia), Brawijaya University (Indonesia), Gadjah Mada University (Indonesia), Bogor Agricultural University (Indonesia), Université de Cocody (Cote d'Ivoire), Universite D'Adobo-Adame (Cote d'Ivoire), Universidade Veracruziana (Mexico), Instituto Polytecnico (mexico), Leuven (Belgium), Paris (France), Bayreuth and Hohenheim (Germany), SLU (Sweden), NAU (Norway), Cornell (USA), Wisconsin-Madison (USA), Ohio State (USA), Colorado State University (USA), East Anglia (UK), Queen Mary University (USA), Michigan State University (USA), ITC (The Netherlands) University of Exeter (UK), and Wageningen University and Research Centre (Netherlands). ***Regional Consortia:*** AFNET, MIS, CONDESAN; ***NGOs:*** CARE, World Vision; CIPASLA, CIPAV.

Project Changes: TSBF-CIAT has developed and published a document on strategy and work plan for 2005-2010. CIAT activities of the Systemwide Program on SWNM are incorporated. Project logframe has been aligned to support goals of MDG, MEA and CGIAR Science Council priorities.

PE-2 Project Log Frame as in CIAT MTP 2005-2007

Project: Integrated Soil Fertility management in the tropics
Project Manager: Nteranya Sanginga

Narrative Summary	Measurable Indicators	Means Of Verification	Important Assumptions
Goal To strengthen national and international capacity to manage tropical ecosystems sustainably for human well-being, with a particular focus on soil, biodiversity and primary production; to reduce hunger and poverty in the tropics through scientific research leading to new technology and knowledge; and to ensure environmental sustainability through research on the biology and fertility of tropical soils, targeted interventions, building scientific capability and contributions to policy.	The principles of sustainable development integrated in country policies and programs. Reversal of the losses of environmental resources, especially loss of soil and below-ground biodiversity. Capacity built in tropical countries for sustainable management of natural resources. Developmental and environmental objectives taken inter-dependently.	National plans, human development and environment reports. Data from international organisations (UNEP, FAO, CG-institutes) that monitor the state of environmental resources. Impact studies, IARC and NARS reports, papers and publications.	Continued government and donor support. Sustained political and financial support for agricultural research and protecting the environment. Linkages maintained among research and development organizations.
Purpose To support the livelihoods of people reliant on agriculture by developing profitable, socially-acceptable and resilient agricultural production systems based on Integrated Soil Fertility Management (ISFM); to develop Sustainable Land Management (SLM) in tropical areas through reversing land degradation; and to build the human and social capital of all TSBF-CIAT stakeholders for research and management on the sustainable use of tropical soils.	By 2015, in at least two countries in each of the major tropical regions where TSBF-CIAT works, the number of rural people in extreme poverty reduced by 20%. By 2010, capacity built in at least three partner countries by at least three of the following: - a national level policy or legislative instrument developed by reference to a TSBF output. - all soil-related national institutions linked to TSBF networks with at least 50% of their scientists engaged in TSBF-inspired topics. - extension agencies and/or NGOs take up TSBF outputs to apply in their work programs. - farmers' organisations and/or civil society apply TSBF outputs in their plans and work. By 2008, TSBF-CIAT scientists are leading globally-funded research on at least three topics of key relevance to the international community (as identified in GEF, MDG, MEA, CGIAR mission and goal statements).	Reports of collaborating national and international institutions – in poverty reduction and sustainable development. National agencies surveys, development plans and reports. International agencies mission and goal statements related to TSBF-CIAT annual reports and accounts.	Poverty reduction strategies remain central to human development support and funding. TSBF stakeholders remain engaged with TSBF-CIAT strategic priorities and/or TSBF management continues to adapt and innovate in response to changing priorities. Funding for research on globally-important issues continues.
Output 1 Biophysical and socioeconomic processes understood, principles and concepts developed for protecting and improving the health and fertility of soils.	By 2006, indicators of soil health and fertility at plot, farm and landscape scales identified. By 2008, practical methods for rapid assessment and monitoring of soil resource base status developed. By 2010, decision tools for soil biota, nutrient and water management developed and disseminated to stakeholders.	Annual Reports/ publications. Reviews published. Documents of synthesized results. Detailed tables published in Annual Report. Decision guides for ISFM developed.	Sufficient operational funds for soil and plant analyses. Literature on constraints available. Farmers continue to participate. Projects SN-1, PE-3 and PE-4 actively participate. Active collaboration with participatory research project (SN-3), RII and NARS.

Narrative Summary	Measurable Indicators	Means Of Verification	Important Assumptions
Output 2 Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical and socioeconomic processes.	By 2006, decision support framework for ISFM developed, tested with and made available to stakeholders in at least 2 benchmark countries. By 2008, communities in at least 3 countries demonstrate and test direct or indirect management options that enhance locally important ecosystem services using BGBD. By 2010, local baselines and interviews show that farmers' understanding of soil processes is demonstrably enhanced within community-based experimentation in at least 5 benchmark sites.	Annual Reports/ publications. Scientific publications. Soil and crop management guidelines published. Decision support systems developed. Annual reports.	Sufficient operational funds for soil and plant analyses. Literature on constraints available. Farmers continue to participate. Projects SN-1, PE-3 and PE-4 actively participate. Active collaboration with participatory research project (SN-3), RII and NARS.
Output 3 Partnerships developed and capacity enhanced for improving the health and fertility of soils of all stakeholders.	By 2005, AfNet, MIS, SARNET and BGBD Networks restructured and strengthened. Publications (i.e., journal papers, books, extension materials, policy briefs, etc.), workshops, documentaries, field days implemented by each project. By 2010, tools for dissemination of research knowledge developed by each project. By 2010, appropriate policies and innovative institutional mechanisms developed and promoted.	Annual Reports/ publications. Scientific information (theses, publications, workshop reports, project documents) disseminated to network members and all stakeholders. Network trials planned and implemented with partners. Degree-oriented and on-the-job personnel trained (Farmers, NARS, NGO's).	Continued interest/participation of NARS and ARO partners, and national and international universities. Continued support for collaborative activities e.g. Challenge programs.
Output 4 Improved rural livelihoods through profitable, diverse and intensive agricultural production systems.	By 2006, cereal-legumes and livestock systems, with nutrient use efficiency as an entry point, tested and adapted to farmer circumstances. By 2006, Quesungual and other related agroforestry systems, with water conservation as entry point, including crop diversification strategies, tested and adapted to farmer circumstances. By 2006 increase farm income and production in at least 20 pilot sites in at least 6 countries. By 2007, banana and cassava based systems, with the relation between pest, diseases and ISFM as entry point, including novel cropping sequences, tested and adapted to farmer circumstances. By 2008 improved production systems have triple benefits of food security, income and environmental services. By 2008, farmers are testing and adapting improved production systems in at least 15 sites in 5 countries. By 2010, validated intensive and profitable systems are being demonstrated, promoted by partners and adopted by farmers in 10 countries.	Annual Reports/ publications. Farmer's surveys. Regional/national production statistics. Land use surveys (satellite imagery, rapid rural appraisal).	Land survey data available. Farmers adopt new technologies. Socioeconomic conditions are favorable for achieving impact. Adequate resources available for soils research.
Output 5 Sustainable land management for social profitability developed, with special emphasis on reversing land degradation.	By 2007, identification, characterization and monitoring of degraded lands available for at least 2 regions. By 2008 methods for socioeconomic evaluation/valuation of ecosystem services for trade-off and policy analysis used, at least in 2 humid and 2 sub-humid Agro-ecological zones. By 2010, 30% of partner farmers in pilot sites used SLM options that arrest resource degradation and for increased productivity in comparison with non-treated farms.	Annual Reports/ publications. Farmers surveys. Regional/national production statistics. Land use surveys (satellite imagery, rapid rural appraisal).	Land survey data available. Farmers adopt new technologies. Socioeconomic conditions are favorable for achieving impact. Adequate resources available for land management research.

PROJECT PE-2: INTEGRATED SOIL FERTILITY MANAGEMENT IN THE TROPICS (CIAT-MTP 2006-2008)

	Outputs	Intended User	Outcome	Impact
OUTPUT 1	Biophysical and socioeconomic processes understood, principles, concepts and methods developed for protecting and improving the health and fertility of soils	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Principles, concepts and methods inform technology and system development	Improved soil health and fertility contribute to resilient production systems and sustainable agriculture
Output Targets 2006	Impact of three contrasting cropping systems on productivity and nutrient dynamics in hillsides and savannas quantified	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners testing the promising production systems	
	Standard methods for BGBD (belowground biodiversity) inventory published	CGIAR, ARIs, researchers from NARS and local universities, regional consortia	Partners and other global scientists using standard methods for BGBD inventory	
	At least three indicators of soil health and fertility at plot, farm and landscape scales in hillsides of Africa identified	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners begin validating indicators of soil health and fertility	
Output Targets 2007	At least three indicators of soil health and fertility at plot, farm and landscape scales in acid soil savannas identified	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners begin validating indicators of soil health and fertility	
	Land use intensity impact on BGBD evaluated in seven tropical countries participating in the BGBD project	Scientists participating in the BGBD project, ARIs, CGIAR, researchers from NARS and local universities, and farmers	Links between BGBD and land use management established and used as basis for developing sustainability in tropical farming systems	
	At least two indicators of soil quality used for farmer's decision making in hillsides agroecosystem;	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners incorporate farmer decision making in new proposals and on–going activities	
Output Targets 2008	Practical methods for rapid assessment and monitoring of soil resource base status developed	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners are using the methods with farmers	

	Outputs	Intended User	Outcome	Impact
	The social, gender, and livelihood constraints and priorities affecting the sustainable use of soils have been identified, characterized, and documented through case studies using innovative methods	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners are working to overcome the identified constraints with new proposals and on-going research	
OUTPUT 2	Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical, socio-cultural and economic processes	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Technologies, systems and soil management strategies \adopted and adapted through partnerships	Adapted technologies contribute to food security, income generation and health of farmers
Output Targets 2006	Decision support framework for ISFM developed, tested with and made available to stakeholders in at least two benchmark countries in Africa	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Partners incorporating the DSS in new proposals and on-going research efforts	
	Cereal-legumes and livestock systems, with nutrient use efficiency as an entry point, tested and adapted to farmer circumstances in hillsides of Africa	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Cereal-legume systems and soil management strategies adopted and adapted through partnerships	
Output Targets 2007	Banana, bean and cassava-based systems, with the relation between pest, diseases and ISFM as entry point, including novel cropping sequences, tested and adapted to farmer circumstances in Africa	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Banana, bean and cassava-based systems and soil management strategies adopted and adapted through partnerships	
	Cereal-legumes and livestock systems, with nutrient use efficiency as an entry point, tested and adapted to farmer circumstances in acid soil savannas	CGIAR, ARI, researchers from NARS and local universities	Cereal-legume systems and soil management strategies adopted and adapted through partnerships	
Output Targets 2008	Communities in at least three countries demonstrate and test direct or indirect management options that enhance locally important ecosystem services using BGBD	BGBD network, CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers and global conservation organizations	Researchers, farmers, land users and policy makers and global conservation organizations increase their awareness of the benefits of conserving and managing BGBD	

	Outputs	Intended User	Outcome	Impact
	Quesungual and other related agroforestry systems, with soil and water conservation as entry point, including crop diversification strategies, tested and adapted to farmer circumstances in Central America	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, and regional consortia	Quesungual system and soil management strategies adopted and adapted through partnerships	
OUTPUT 3	Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Strengthened and expanded partnerships for ISFM facilitate south-south exchange of knowledge and technologies	Improved institutional capacity in aspects related to ISFM and SLM in the tropics contribute to agricultural and environmental sustainability
Output Targets 2006	At least two capacity building courses on ISFM held	AfNet, MIS	Partners incorporating new knowledge and skills in new proposals and on-going research efforts	
	At least five capacity building courses on BGBD held at the global level and more at participating country level	BGBD partners, researchers, local universities and NGOs	Partners incorporating new knowledge on BGBD and skills in new proposals and on-going research efforts	
Output Targets 2007	Strategy for building capacity for SLM is developed with partners	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	TSBF-CIAT scientists and partners lead globally-funded research on at least three topics of key relevance to the international community (as identified in GEF, MDG, MEA, CGIAR mission and goal statements)	
	At least three capacity building courses on ISFM held by AfNet and MIS	AfNet, MIS	Partners incorporating new knowledge and skills in new proposals and on-going research efforts	
	Books, web content and papers produced by partners in BGBD project both north and south in seven tropical countries	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Partners incorporating new knowledge and skills in new proposals and on-going research efforts	

	Outputs	Intended User	Outcome	Impact
Output Targets 2008	Farmer-to farmer knowledge sharing and extension through organized field trips and research activities result practices in at least two sites	Researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers realize benefits of knowledge sharing	
	Web content in the BGBD website enhanced to contain data and information on BGBD taxonomy and species identification	Researchers, CGIAR, ARI, local universities	Increased number of biodiversity scientists use the website for proper identification and classification of soil biota to species level	
OUTPUT 4	Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Partners promoting resilient production systems with multiple benefits (food security, income, human health and environmental services)	Improved resilience of production systems contribute to food security, income generation and health of farmers
Output Targets 2006	Crop components and soil management technologies of improved systems promoted by partners in African hillsides	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers adopting improved system components, including crops and soil management technologies	
	Management practice options that increase or maintain BGBD in benchmark agroecosystems demonstrated by partners and farmers in seven tropical countries participating in the BGBD project	Researchers from NARS, local universities and farmers	BGBD and land use management strategies that enhance crop yields and ecosystem services produced and documented	
Output Targets 2007	Crop components and soil management technologies of improved systems promoted by partners in acid soil savannas	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers	Farmers adopting improved system components, including crops and soil management technologies	
	Crop-livestock systems with triple benefits tested and adapted to farmer circumstances in hillsides	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers are testing and adapting improved production systems in at least 15 sites across five countries	

	Outputs	Intended User	Outcome	Impact
	Strategies of BGBD management for crop yield enhancement, disease control, and other environmental services demonstrated in seven tropical countries participating in the BGBD project	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers and governments adopting BGBD technologies in crop production and ecosystems services	
Output Targets 2008	Improved production systems having multiple benefits of food security, income, human health and environmental services identified	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Market-led hypothesis is incorporated in systems experimentation; Different partners linking food security, environmental sustainability and income generation to health	
	Crop-livestock systems with triple benefits tested and adapted to farmer circumstances in savannas	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Farmers are testing and adapting improved production systems in at least 15 sites across five countries	
OUTPUT 5	Options for sustainable land management (SLM) for social profitability developed, with special emphasis on reversing land degradation	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, young professionals, policy makers	Principles of sustainable land management integrated in country policies and programs	Reversing land degradation contribute to global SLM priorities and goals
Output Targets 2006	Potential for carbon sequestration estimated for at least one tropical agroecoregion	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Regional governments develop CDM projects based on the knowledge of carbon sequestration potential	
	Economic valuation of legume nodulating bacteria and soil structure carried out in at least five countries participating in the BGBD project	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Visibility of BGBD economic viability and BGBD technologies appreciated and used by farmers, and disseminated by local, national and regional governments	
Output Targets 2007	Decision tools (GEOSOIL; Decision Tree) available for land use planning and targeting production systems in acid soil savannas	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Local organizations using the decision tools for land use planning	

	Outputs	Intended User	Outcome	Impact
	Biophysical, social and policy niches in the landscape for targeting SLM technologies and enhanced ecosystem services identified and prioritized	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Methods of SLM are incorporated in the design of landscape research	
Output Targets 2008	Methods for socio-cultural and economic valuation of ecosystem services developed and applied for trade-off and policy analysis used in at least in 2 humid and 2 sub-humid agroecological zones	CGIAR, ARI, researchers from NARS and local universities, BGBD network, NGOs, farmers, regional consortia, policy makers	Methods of SLM are incorporated in the design and evaluation of landscape research	
	In at least four of the countries participating in the BGBD project, policy stimulated to include matters related to BGBD management, and sustainable utilization.	CGIAR, ARI, researchers from NARS and local universities, NGOs, farmers, regional consortia, policy makers	Policy issues related to BGBD acquisition, exchange, intellectual property rights (IPR), benefits sharing, etc. included in local, national and regional government policies	

3. RESEARCH HIGHLIGHTS

Output 1: Biophysical and socioeconomic processes understood, principles, concepts and methods developed for protecting and improving the health and fertility of soils

Water harvesting and interactions with dry mixtures of phosphate rock (PR) and water-soluble P in West African Drylands: Collaborative research of TSBF-CIAT with its West African partners (ICRISAT, INRAN, INERA) and with the Financial Support of UNEP-GEF for the DMP project, sorghum production in the dry sahelian zone increased by 300-800% following different technologies combining water harvesting and nutrient management. The water harvesting technologies include use of Zai, halfmoon or stone bounds and these could be accompanied by additions of small quantities of manure, mineral fertilizers or their combination. This research has also shown that nutrients are more important than water even in the dry areas. In 2005, use of Zai alone in Tougouri, Burkina Faso for example, performed better than the use of either nitrogen or phosphorus fertilizer. Combinations of water harvesting and nutrient application highly increased yields due to better utilization of inorganic fertilizers. Even when both Zai and halfmoon technologies were tested with combinations of water soluble P and phosphate rock in farmers' fields, similar yield increases were observed. From the studies, combining ¼ of water soluble P and ¾ of natural PR lead to the same yield as treatment where water soluble P was 100%. Water harvesting through Zai, half moon, use of tied ridges and stone bounds combined with nutrients such as manure, inorganic N and P and phosphate rock are some of the soil improvement technologies being scaled up in DMP West African countries by AfNet-TSBF, ICRISAT and other partners.

Overcoming phosphorus (P) deficiency in West African farming systems through Hill Placement and improving phosphate rock (PR) efficiency: Work done by TSBF-CIAT and its partners for several years with funding from Rockefeller Foundation focusing on phosphorus (P) availability has resulted in technologies that are now being taken up by farmers. The focus on P was because it is the most limiting nutrient to cop productivity in West Africa and about 80% of the African soils have inadequate supply. The technologies include hill placement of small quantities of P rather than broadcasting and combining PR with some water-soluble P. The work has shown that leguminous crops and cover crops in natural and managed fallows can take full advantage of biological nitrogen fixation in the presence of adequate P levels in the soils. It focused on utilizing PR deposits that are plenty in Africa by increasing their activity and suitability for direct application through use of PR together with water-soluble P. For several years, we have observed that the efficiency of Phosphate Rocks (PRK and PRT) can be increased above that of soluble P when a little amount of the soluble P is combined with the PR. Combining PR with 25% water-soluble P in has not shown any differences from its combination with 50%, 75% or 100% water soluble P. This clearly shows that placement of small quantities of water-soluble P fertilizers can improve the effectiveness of phosphate rock. To increase the impact of this outcome, Governments in West African Countries will require to invest more in bringing PR closer to the people or by facilitating this process to be carried out by entrepreneurs.

Strategic research in Latin America contributes to research for development in Africa: A participatory approach and a methodological guide were developed to identify and classify local indicators of soil quality and relate them to technical soil parameters and thus develop a common language between farmers, extension workers and scientists. This methodological guide was initially developed and used in Latin America and the Caribbean-LAC (Honduras, Nicaragua, Colombia, Peru, Venezuela, Dominican Republic), and was later improved during adaptation and use in eastern African (Uganda, Tanzania, Kenya, Ethiopia) through a South-South exchange of expertise and experiences. The aim of the methodological guide is to constitute an initial step in the empowerment of local communities to develop a local soil quality monitoring and decision-making system for better management of soil resources. Impacts on higher education (Makerere University, Uganda), on a regional organization (African Highlands Initiaive, Tanzania) and on an international NGO (CARE International, Kenya) have been recently documented. Another example highlighted in several 2005 publications includes the use of the In Vitro Dry Matter Digestibility (IVDMD) lab assay as an excellent predictor of decomposition and N release in the soil, especially because it has important implications in resource savings when screening multi-purpose plants to be used as green manures.

Knowledge of spatial and temporal dynamics of soil macrofauna in the Quesungual Agroforestry System allows improved soil biota management: The activities of soil animals such as earthworms, ants and termites can improve soil structure, organic matter decomposition and nutrient cycling. In marginal environments, soil fauna can make an important contribution to soil quality and soil fertility. The rugged terrain of the isolated southern Lempira department in Honduras represents one such marginal environment, where the traditional slash-and-burn agriculture has been gradually, and successfully, replaced with slash-and-mulch agroforestry known as the "Quesungual System". The dramatic increase in organic matter input following slash-and-mulch, the introduction of a tree overstorey within fields, and the patchwork landscape of secondary forest, agroforestry and pasture that exists within the study area suggest likely increases in soil macrofauna abundance and diversity. During quantification and characterization of the soil macrofauna community one of the most important results was that absolute numbers of soil macrofauna in soils under Quesungual were much higher than expected, when compared with other agricultural systems of the semi-humid tropics. Numerically, termites, ants and earthworms were the most abundant animals, in that order. In terms of biomass, earthworms were dominant. Farmers' knowledge synthesized during participatory mapping of soil quality on-farm was instrumental to allow relevant stratification needed to guide spatially explicit sampling and spatial analysis of soil macrofauna. Spatial distribution of soil fauna distribution as reflected by earthworm casts and ant nests indicate that earthworm abundance is positively affected by the abundance of pruned trees, while ant abundance is negatively affected by tree abundance. This research has important implications for farm management, as it shows that farmers can manage litter cover and macrofauna activity by manipulating pruned tree density and distribution.

Determining the effects of tillage systems on soil physical properties, root distribution and maize yield on a Colombian acid-savanna Oxisol: Tillage system may affect many soil properties, which in turn may alter the soil environment and consequently may impact on root growth and distribution, and crop yield. In 1993, a long-term field experiment on sustainable crop rotation and ley farming systems was initiated on a Colombian acid-savanna Oxisol to test the effects of grain legumes, green manures, intercrops and leys as possible components that could increase the stability of systems involving annual crops. Five agropastoral treatments (maize monoculture, maize-soybean rotation, maize-soybean green manure rotation, native savanna, maize-agropastoral rotation) under two tillage systems (no tillage and minimum tillage) were investigated. Lower bulk density and higher total porosity for all treatments and soil layers was found in no-till as compared to the minimum tillage system. Between the two tillage systems, significantly higher maize grain yields were obtained under no-till agropastoral treatments as compared to the same treatments under minimum tillage. Maize yields on native savanna soils were markedly lower than in the rest of the treatments, indicating the need for improved soil conditions in subsoil layers for root growth of maize.

Determining the effects of tillage systems on soil organic matter pools and soil phosphorus fractions and maize yield on a Colombian acid-savanna Oxisol: Soil organic matter and phosphorus fractions play a key role in sustaining the productivity of acid-savanna Oxisols and are greatly influenced by tillage practices. In 1993, a long-term field experiment to test the sustainability of crop rotation and ley farming systems was initiated on the acid-savanna soils of Colombia. Five agropastoral treatments (MMO-maize monoculture, MSR-maize-soybean rotation, MGM-maize-soybean green manure rotation, NSC-native savanna (control) and MAP-maize-agropastoral rotation) under two tillage systems (minus chisel-MC and plus chisel-PC) were investigated. The effects of chisel (vertical) tillage on soil organic matter (SOM) and phosphorus (P) fractions as well as maize grain yield under the five treatments were evaluated, seven years after establishment of the experiment. Results showed that the weights and nutrient contents of the SOM fractions decreased in the order LL (light Ludox fraction) > LM (intermediate Ludox fraction) > LH (heavy Ludox fraction). Treatment MGM had significantly higher values for the P fractions under both tillage systems. However, PC tillage resulted into slightly higher maize grain yields as compared to MC. Within MC tillage system, the trend of maize grain yield was MGM > MMO > MSR > MAP > NSC, while for the PC tillage system, it was MGM > MSR > MMO > MAP > NSC. Future research should focus on integrated approaches that combine biophysical and socio-economic parameters to evaluate the sustainable productivity of Colombian savanna Oxisols.

Identifying and overcoming the limitations for implementing conservation farming technology in the Fuquene watershed (Colombia) by integrating socioeconomic and biophysical research with financial mechanisms: Reduced tillage, rotations with green manures and direct drilling are agriculture conservation practices selected by CONDESAN, CIAT and GTZ (WFCP project) to be promoted in order to reduce the deposition of sediments, N and P in the Fuquene Lake, which is suffering an advanced process of eutrophication. Previous studies demonstrated that this alternative could reduce the negative environmental externalities by about 50% as the net income and employment opportunities are increased. These studies were: 1) Identification of point and non point sources of pollutants; 2) Prioritization of areas according with their responsibility in the lake eutrophication; 3) Application of experimental economics methodologies to explore willingness of water users and farmers to cooperate for modifying negative environmental externalities, 4) Determination of poverty profiles and how are spatially distributed; and 5) Ex ante impact assessment of changing conventional tillage practices by farming conservation practices. Although, these studies showed that by incorporating conservation agriculture practices the net income is increased, the technological change is not reached readily since farmers' cash flows are unable to cover the required additional investment to incorporate green manures prior to the conventional crop is sown. For these reasons, the project designed a financial mechanism to investigate if the suspected restricted financial capacity of small farmers was constraining a massive technological change in the watershed. To reach this objective CONDESAN-GTZ made an agreement with the regional environmental authority (CAR) to assure the technical assistance needed for the implementation of the practices. Also, two farmers associations were introduced to the partnership acting as direct beneficiaries of the credits and also as intermediaries between CONDESAN and the smallest farmers who do not belong to the associations. These development actions are not only promoting technological changes but are creating in situ research scenarios for investigating the real constrains for using the soils in a sustainable manner. Therefore, this project expects to determine the biophysical ex post impact of these practices on the soils and lake conditions and the social and economic benefits caused by the technological change. If the results are positive, these practices will be incorporated as an alternative that can be compensated by a payment for environmental service (PES) scheme also promoted by the project.

Output 2: Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical and socioeconomic processes

Progress in defining the key principles behind the successful adoption of Quesungual slash and mulch agroforestry system (QSMAS): The QSMAS is an alternative to the slash and burn management system. It is based on planting annual crops (maize, sorghum, beans) and pastures under an indigenous slash and mulch management system. It combines the regrowth of native forest vegetation with no burning and zero tillage/direct planting operations on a permanent soil cover. More than 6,000 farmers covering an estimated area of 7,000 ha, who have adopted the QSMAS system during the last ten years in Honduras, have increased crop yields by more than 100% (maize from 1200 to 2500 kg/ha, beans from

325 to 800 kg/ha) in comparison with the traditional slash and burn system. In 2004, TSBF-LA and MIS consortium in Central America obtained special project funding from the Water and Food CP to conduct a collaborative research program to determine the key principles behind the social acceptance and biophysical resilience of QSMAS. The specific objectives of the project are: 1) To assess socio-economic and biophysical context of QSMAS; 2) To define QSMAS management concepts and principles and to develop relevant tools to monitor soil and water quality; 3) To evaluate and document potential areas suitable to QSMAS and 4) To develop tools for dissemination, adaptation and promotion of the QSMAS management strategies. During this year, field research and validation activities have been implemented in Honduras and Nicaragua. Preliminary results indicate that soil losses due to erosion are negligible and water conservation is increased because of permanent mulch on the soil. Excess water leaving the system by runoff is almost clean and can be used by downstream users. However, there are methodological challenges to determine water dynamics in the soil because of the high proportion of stones in the soil. Preliminary results from the plot experiments on farmers' fields are showing strong interactions among key factors such as soil fertility, water availability and crop productivity.

Adoption of new soil conservation technologies in the Llanos of Colombia - Arable layer building technology: As a result of CIAT's collaborative research activities with regional partners (Corpoica, Pronatta and Unillanos) and with the financial support from the Ministry of Agriculture and Rural Development (MADR) and Colombian Science Foundation (COLCIENCIAS), a series of soil improvement and conservation practices have been developed. These practices focus on arable layer building technologies —part of the soil profile that can be modified through a combination of biological and physical management— in soils of the well-drained savannas of the Llanos of Colombia. These practices include use of proper crop and pasture rotations in agropastoral systems. Practices for arable layer building include a vertical corrective tillage using rigid chisels, correction of nutrient deficiencies in soil and sowing of acid soil adapted tropical forages with vigorous root systems and field crops with greater yield potential. Farmers in the Llanos region of Colombia are the main users of this outcome. Farmers in the past attempted to establish crops without adequate soils management and used non-adapted pasture and crop germplasm, and consequently experienced large economical failures. In contrast to their previous experiences, utilization of soil conservation methodologies together with the use of improved germplasm have shown significant advantages in productivity and in economic returns to the investments made. Recent impact studies conducted by CIAT and its partners indicated that the productivity gains constitute the principal benefit for those who apply soil conservation practices in the Llanos. Research publications, technical bulletins, extension brochures and progress reports in both English and Spanish documented the development of technologies. It is considered that for achieving wider impacts of arable layer soil management technologies, investment by the Colombian government in improving road infrastructure is critical.

Output 3: Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils

Strengthening research for development capacity of the AfNet: The year 2005 was marked by a continued growth of AfNet membership to over 350 members. During this period, AfNet continued the implementation of the Network trials located in over 80 sites in different agroecological zones distributed in East, South, Central and West Africa regions. These experiments have increased understanding on the sustainable management of the natural resource base and have generated and demonstrated new technologies that can help boost food production among the smallholder farmers in the continent. AfNet Steering Committees meeting was held during which the role of the Network in achievement of the TSBF Strategy was discussed. AfNet successfully organized two training courses: Participatory Approaches to Research and Scaling Up, attended by 37 participants, and the Decision Support Systems for Agrotechnology Transfer (DSSAT) training workshop attended by 29 participants. AfNet ensured the review of over 100 papers presented during the Yaoundé Symposium in readiness for the publication of the AfNet Symposium Book and the Special Issue in Nutrient Cycling in Agroecosystems in 2006. Several proposals were also developed of which 10 received funding from various donors. AfNet published the TSBF newsletter, *The Comminutor*, which highlighted research issues in Latin America. The Network continues to be a pan African Network and will continue in its effort to coordinate and promote information sharing for the sustainable and integrated management of natural resources in the continent.

Advances in Conservation and Sustainable Management of Below-ground Biodiversity (CSM-BGBD) Project: The year 2005 was a major milestone for the CSM-BGBD project. It is the year when nearly all partners in the project met in a joint meeting in Brazil to present the results from the BGBD inventory they had carried out in their individual countries. Brazil, Cote d'Ivoire, India, Indonesia, Kenya, Mexico and Uganda were all represented by a minimum of five participants. The meeting also had all the technical advisors, the steering committee members and the project advisory committee members attending and reviewing the project progress. The mid-term reviewers of the project were also in the meeting held in April 2005 in Manaus Brazil. Technical papers were presented covering: Benchmark area descriptions and socio-economic characterization, Inventory of soil macro-fauna, Inventory of nematodes and Meso-Fauna, The inventory of legume nodulating bacteria, arbuscular mycorrhizal fungi and ectomycorrhiza, The inventory of pathogenic and antagonistic fungi and insect pests, Presentation of the standard methods, Ecosystem service and soil quality indicators, Analysis of BGBD at landscape level and in different land use intensities, Output of economic valuation of BGBD for different soil functions and environmental services, Information management and data sharing in the project. The overall conclusion from the technical reviewers during the meeting was that the project had succeeded in agreeing on appropriate standard methods for most of the functional groups mandated and has used them to assemble a unique and comprehensive dataset during the period since the last Annual Meeting in 2004. Apart form these technical observations; the project was subjected to a mid-term review as was required of the project and contained in the project document. The reviewers of the project, Professor Eric Smaling of ITC-The Netherlands and Professor Mateete Bekunda of Makerere University-Uganda, returned a final mid-term review rating of 'Good' for the project and recommended its continuation into the second phase that has now been approved by the Global Environmental Facility (GEF). There is ongoing progress of publishing all the technical papers presented in a Book to be released in late 2006. Partners during the BGBD annual meeting produced a total of 71 papers and four discussion papers in ecosystems services, land use intensity quantification, economic valuation of BGBD and data sharing and intellectual property rights. BGBD scientists participated in three global training workshops, two in Nairobi (ants and termites characterization) and one in India on mycorrhizal fungi. Individual countries organized workshops and training courses for their country partners and project executioners.

Nicaraguan farmers start validating the management principles of Quesungual slash mulch agroforestry systems (QSMAS) in their own farms: Twenty farmers from drought-prone areas of Nicaragua visited the farmers that are practicing the Quesungual on their farms in Honduras. The main objective of their visit was learning from farmers practicing the system the main management principles and benefits of the Quesungual. Six months later six farmers from Somotillo, Nicaragua showed their own Quesungual plots to a group of researchers from the MIS consortium. They were very excited about the good adaptation of the system and expressed their willingness to teach other farmers from similar regions the benefits of the Quesungual. This type of farmer-to-farmer exchange proved to be a dynamic mechanism of knowledge sharing and an effective way to disseminate ISFM principles.

Scaling out conservation farming experience in Fuquene (Colombia) to other Andean watersheds: Ambato (Ecuador) and Jequetepeque (Peru): Ex-ante evaluation of land use alternatives had demonstrated that conservation agriculture is an SLM alternative for improving environmental services and rural livelihoods. Based on Fuquene (Colombia) experience, the special project "Payment for

Environmental Services" (CONDESAN-GTZ-CIAT) of the WFCP is promoting a capacity building strategy for enhancing other pilot sites farmers' capacities in conservation agriculture. The strategy has started with training courses held in the conservation agriculture pilot site (Fuquene) and subsequent courses held directly at the extrapolation sites. The participants for courses were selected according with their previous commitment to apply the learned practices in their own farms. The project, through its extension partners (GTZ), will provide continuous technical assistance for a year in order to ensure that the technology is properly applied during green manures and commercial crops sowing. In Peru, strategic alliances between the project local partner (CEDEPAS) and the farmers were created in order to establish pilot farms. Complementary research activities are conducted in order to measure the impact of these practices on soil physical properties and incidence of crop diseases. For 2006, pilot implementation of these soil conservation practices was agreed between a community-based organization and the project in Ecuador. The monitoring of impacts will be measured by CONDESAN and CIAT.

Output 4: Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems

Improving food security for western Kenyan farm households with integrated soil fertility management for local vegetable crops: We analyzed the food security in vegetable yields of subsistence households, which were producing kale for market and those, which were cultivating traditional African vegetables (TAVs) for home consumption. By comparing kale-producing households with TAV producing households in terms of the allocation of labour and capital and the coping mechanism enacted to cope with transitory food insecurity, we found that households producing kale have a higher level of food security. This increased food security stems from three key factors: the malleability of kale to be a vegetable and a high-value cash crop; the dedication of all households members to the daily maintenance of kale; and the location of farms adjacent to a water source. These three key factors allow for women to be able to access kale for home consumption, increase the purchasing power of households, and also, boost the total yield of vegetables cultivated on the farm. TAV producing households were found to be vulnerable to an insufficient vegetable supply largely because of geographic location and the overburdening labour demands on the women to singularly produce all household vegetables.

Improved decision making for achieving triple benefits of food security, income and environmental services through modeling cropping systems in Ethiopian Highlands: Food security in the Enset-based Ethiopian highlands is constrained mainly by land degradation, land fragmentation and limited access to technologies and skills. Enset (Enset ventricosum) is a perennial herb with edible corm, supporting about 13 million people in Ethiopia. A household survey, supported by field measurements, was conducted over three years (2000–2002) with 24 representative farmers to identify their production objectives and to quantify their available land resources, cropping system, crop yields and market price, for developing models to facilitate their decision making. Farmers identified three major production objectives depending on their household priorities, socio-economic status and resource base. In Scenario I, farmers were primarily interested in producing enough food from their farm. In Scenario II, they wanted food security and to fulfil their financial needs. In Scenario III, farmers were interested solely in generating cash income, regardless of its effect on food production. The change from current production systems to Scenario I offers high quality livestock feed, while Scenario III offers low quality livestock feed whereby about 84% of the feed is coming from coffee husk. Moreover, a shift from the current system to Scenario I would not have any effect on the level of soil erosion, while a shift to Scenario II and III will reduce soil erosion by about 39 and 52%, respectively, mainly as a result of expansion of the area of perennial crops.

Output 5: Sustainable land management for social profitability developed, with special emphasis on reversing land degradation

Evaluation of the Dalhem Desertification Protocol to evaluate land degradation problems drought-prone areas of sub-humid tropics: An international workshop meeting was hosted by the MIS (Manejo Integrado de Suelos) Consortium, in Honduras as part of collaborative activities with ARIDnet, a collaborative research network on desertification supported by the National Science Foundation. The objective of the workshop was to validate the Dalhem Desertification Paradigm (DDP) to prioritise policy and management interventions through an integrated analysis (at multiple spatial scales) of both biophysical (meteorological and ecological factors) and socio-economic (human factors) dimensions of land degradation. The Honduras workshop extended the application of the DDP to land degradation and recovery of steepland agricultural systems in Central America, including an assessment of the unique "Quesungual" slash and mulch agroforestry system. The Quesungual system has already been adopted by 6,000 farmer households in Honduras, resulting in a two-fold increase in crop yields and cattle stocking rates and significant reduction in costs associated with agrochemicals and labour. Working as a team of local and international experts, the workshop addressed a complete DDP-based analysis of the opportunities for -- and limitations to -- the recovery of an agroecological system in the Guarita municipality, and the potential application of the Quesungual slash and mulch agroforestry system. In addition to local dissemination of the results, we plan to synthesize and submit the results of the workshop to a peer-reviewed international journal, with authorship open to all participants.

Watershed analysis to identify niches for sustainable land management and use - two case studies: The special project "Payment for Ecosystem Services" financed by the WFCP is applying in their different pilot sites a methodology for integrated watershed analysis. The results of this analysis are providing guidelines to design economic mechanism for ecosystem services conservation. The watershed analysis consisted of: 1) Hydrological modeling using SWAT (Soil & Water Assessment Tool) 2) Socioeconomic and environmental ex ante evaluation of land use and management scenarios, and 3) Determination of opportunity cost for implementing the proposed land use scenarios and valuation of environmental services. During 2005, this approach was applied in the Colombian and Peruvian pilot sites. In Colombia, the results are oriented towards financial mechanism for promoting conservation agriculture. In Peru, the analysis was conducted for the Mayo River watershed located in the transitional zone between the Andes and the Peruvian Amazon. Here, several micro watersheds supply water to various downstream urban aqueducts. However, the replacement of native forest by farming uses seems to be causing the increment of suspended solids in water flows and therefore, of the water treatment cost. With the hydrological analysis 28 Hydrological Response Unites were identified and 8 were prioritized because of their contribution to the environmental externalities (water flows and sediments) and land use change feasibility. In these areas the following scenarios were evaluated: coffee under shade, reforestation and live barriers in traditional production systems, coffee under shade being identified as the most appropriate alternative. Thus, although all potential scenarios produce less quantity of sediments (reduction of about 50%) than the traditional land use system (slash and burn – corn cropping – pastures), the coffee under shade scenario permits to increase farmers' income by 89% and labor employment by 77%. Regarding the design of a PES (payment for environmental services) mechanism, the value of economic payments was determined for each scenario by calculating the cost of a ton of reduced sediments. Thus, one ton of reduced sediments cost 1.31 tons of sediments or $53.6/ha/year during the first two years since this alternative only requires the initial investment as an incentive to replace the traditional land use. Regarding that the 7136 Moyobamba city families are willing to pay $1.5/month as a contribution for promoting watershed resources conservation. It was calculated that it was only required two month of payments to cover the cost required for promoting coffee under shade in the HRU prioritized in the Miskiyacu micro watershed.

Tools for ex-ante evaluation of land use and management alternatives, and for valuation of ecosystem services - ECOSAUT Model: CONDESAN, GTZ and CIAT during the first year of the WFCP project implementation were focused on developing tools for impact assessment of sustainable land uses and valuation of ecosystem services. Therefore, a multicriteria optimization model was designed for the ex-ante analysis, by means of which optimal values of the decision variables that maximize or minimize watershed management objectives can be identified without violating imposed constraints. Linear programming has been applied successfully to measure the tradeoffs between the economic performance of different activities and the environmental externalities. Thus the model permits to evaluate the economic and social potential of the alternatives in improving the quality of life, and the results can stimulate private and official investors to fund some of the alternatives. The project uses the model to support stakeholders in making decisions about multiple land-use options calculating the environmental and socioeconomic costs of changes in land use and technology under different spatial and temporal scenarios. In addition, shadow prices are calculated for determining the price of services and goods that do not have a market price (production of sediments, water flows, etc). This model and approach are being used in the analysis of the five pilot Andean watersheds (Colombia, Ecuador, Peru and Bolivia) in order to support the identification of land use alternatives and management practices that promote the internalization of externalities. The main externalities that are subject of analysis and interventions are retention of sediments, water quantity and quality, and carbon sequestration.

Output 1

Biophysical and socioeconomic processes understood, principles, concepts and methods developed for protecting and improving the health and fertility of soils

Output 1: Biophysical and socioeconomic processes understood, principles, concepts and methods developed for protecting and improving the health and fertility of soils

Rationale

Sustainable agriculture is viewed here from a systems perspective in which the agroecosystem interacts with the atmospheric system and the hydrological cycle as well as with the social and economic systems of the community where it is practiced. This conceptual model transcends the classical boundaries of the biophysical sciences and requires integration with economics, sociology, anthropology and political science. In this context, output 1 deal with developing a mechanistic understanding of the physical, chemical and biological processes regulating soil fertility as a result of intensification and diversification of cropping systems and the recuperation of degraded lands. Nutrient cycling and organic matter dynamics are undoubtedly key drivers of agroecosystem function. There is increasing need, however, to address the issue of scale-dependence of different soil processes ranging from processes at the plant's rhizosphere, to nutrient gradients within farms or greenhouse gas emissions at the landscape scale.

The processes of land conversion and agricultural intensification are a significant cause of biodiversity loss, including that of below ground biodiversity (BGBD), with consequent negative effects both on the environment, ecosystem services and the sustainability of agricultural production. Documentation of BGBD, including the biological populations conserved and managed across the spectrum of agricultural intensification, is an essential component of the information required for assessment of environment-agriculture interactions, as is the evaluation of the impact of agricultural management on the resource base, particularly that of the soil. Soil organisms contribute a wide range of essential services to the sustainable function of agroecosystems among which the biological control of pests and diseases ranks high. The combination of soil fertility and pest and disease management approaches is likely to be a unique opportunity to exploit synergies for the benefit of crop productivity.

Improving the natural resource base without addressing issues of marketing and income generation is often the reason for the lack of adoption of improved farming practices. Participatory approaches have shown considerable potential in facilitating farmer consensus about which soil related constraints should be tackled first. Consensus building is an important step prior to scaling up and out and collective action by farming communities in integrated soil management at the landscape scale. Integration of local and scientific knowledge to develop an integrated or "hybrid" knowledge and thus increased relevance is an overall strategy for sustainable soil management.

Key research questions:

1. Can temporal and spatial heterogeneity at the farm, community, and landscape scale levels be exploited with sustainable land management (SLM) technologies that enhance production and/or improve ecosystem services?
2. How does loss of below-ground biodiversity (BGBD) relate to increasing land use intensity and what are the effects on ecosystem function?
3. To what extent is conservation agriculture applicable to different farming systems?
4. How can we build increased capacity for ISFM by integrating local and technical knowledge?
5. What are the socio-cultural and economic conditions, policies and institutions that influence ISFM?

Milestones 2005

- **Documentation and analysis of farmers'perceptions, preferences, economics and information flow pathways and use of local knowledge within research to extension linkages**

Intensive work with nearly 20 farmers' groups in Western Kenya, and extensive work with farmer groups at other TSBF and AFNET sites elsewhere in Africa, has documented a diversity of rich, context-specific knowledge, priorities, and constraints of smallholders relating to soil fertility management. An innovative community-based learning strategy has successfully stimulated the growth of a "dynamic expertise" that combines local and outsiders' soil fertility management knowledge, with a view towards scaling this expertise up and out of the initial research sites using local networks and institutions.

South-South collaboration through the transfer of concepts and methodological approaches to integrate local and technical knowledge about soils and their management from Latin America to east Africa had measurable impacts on: a) the formal education sector (Makerere University – Uganda), b) a regional research organization (African Highlands Initiative, AHI - Tanzania) and c) a global NGO (CARE-Kenya - Kenya).

- **Role of social differentiation in the creation and maintenance of soil fertility analyzed**

Robust techniques for analyzing heterogeneity of socio-economic and biophysical factors influencing soil fertility management and soil fertility outcomes have now been developed, tested, and applied in a diversity of environments and socio-cultural settings. Strong relationships and patterns of local diversity have emerged, but issues of intra-household differentiation and gender-driven processes of resource access and use could still benefit from more attention. Student theses incorporating these approaches are now well underway.

Highlights

- In a set of medium to long-term trials in the West-African savannas, it was shown that the functioning of the often hypothesized 'safety-net' of trees in a tree-crop intercrop depended on (i) the tree species and on (ii) the presence of a subsoil of suitable quality, i.e., clay enriched and with high Ca saturation. Especially, *Senna siamea* trees were shown to enrich the topsoil with Ca on soils with a clay-enriched subsoil.
- In a long-term hedgerow intercropping trial in West-Africa, it was shown that application of prunings of *Senna siamea* in combination with limited amounts of fertilizer can sustain maize yields above 2.5 tons per hectare for over 15 years. These yields also showed the lowest between-season variation. Sole application of fertilizer resulted in highly variable crop yields between seasons.
- In the Sudan savanna in Burkina Faso, annual application of manure was shown to mitigate the negative effect of ploughing and hand hoeing on soil organic carbon related properties and can therefore contribute to the sustainability of agricultural systems in the Sudano-Sahelian zone.
- In Western Kenya, plant height measurements, taken at any moment after maize flowering, were shown to be good estimators for maize grain yield. This approach proved also a valuable tool to discuss yield variability with farmers.
- Short-term laboratory mineralization data supported the existence of 3 classes of organic resources instead of 4 originally proposed by the Decision Support System for organic N management. It was also shown that direct prediction of decomposition and mineralization from

NIR was faster, more accurate and more repeatable than prediction from residue quality attributes determined using wet chemistry.

- In evaluating the impact of inherent soil properties and site-specific soil management in Western Kenya, it was observed that both above factors explained the variability found in soil fertility status between farms. Texture explained the variation observed in soil C and related total N between sub-locations, whereas P availability varied mainly between farm types as affected by input use. The internal heterogeneity in resource allocation varied also between farms of different social classes, according to their objectives and factor constraints.
- In Western Kenya, in-vitro techniques have shown a high variability within the soybean genepool for triggering suicidal Striga germination. This trait can be used to select specific soybean varieties to be integrated in soybean-cereal rotations in Striga-infested areas.
- Identified, validated, and applied local and technical indicators of soil fertility quality using replicable methodology under smallholder conditions in Kenya to support farmers' experimentation with soil fertility management options.
- Community-based learning and communication strategies to support ISFM research were evaluated collectively by farmers and researchers at a special workshop (June 2005), which contributed to greater farmer involvement in the planning and implementation of the renewed project's second phase.
- The "land degradation" concept was critically reviewed and re-interpreted through dialogue between local and scientific knowledge, updating and prioritizing ISFM interventions appropriate to diverse small-holder conditions.
- Synthesis volumes on the Conservation and Sustainable Use of BGBD published by country teams (Kenya, Indonesia, India) and abstracts from all the country teams' activities were compiled and presented at the annual meeting held in Manaus, Brazil.
- South-South collaboration through the transfer of concepts and methodological approaches to integrate local and technical knowledge about soils and their management from Latin America to east Africa had measurable impacts on: a) the formal education sector (Makerere University – Uganda), b) a regional research organization (African Highlands Initiative, AHI - Tanzania) and c) a global NGO (CARE-Kenya - Kenya).
- In medium-term trials in Colombian Andean hillsides it was shown that the *Tithonia diversifolia* slash/mulch fallow system could be the best option to regenerate soil fertility of degraded volcanic-ash soils after continuous cassava cultivation. Soil parameters most affected by slash/mulch fallow systems included soil total N, available N (ammonium and nitrate), exchangeable cations (K, Ca, Mg and Al), amount of P in the Ludox light fraction, soil bulk density and air permeability, and soil macrofauna diversity.
- Showed that the superior adaptation of *Calliandra calothyrsus* as planted fallow species to infertile soil conditions in Cauca, Colombia is related to its ability to develop fine roots in subsoil layers.
- Field studies on residual P response of maize and bean in volcanic ash soils in Cauca region of Colombia suggested that application of $\geq$ 40 kg P ha^{-1} $year^{-1}$ could gradually build-up soil available P and this practice is better than one time application of large amount of P.
- A methodological approach was developed to study the origin of soil aggregates separated according to visual criteria and determined by comparing their specific organic matter signatures assessed by NIRS to signatures of biogenic structures produced by soil ecosystem engineers.
- Studies in Colombia and Nicaraguan hillsides showed the high potential of NIRS for evaluating soil quality in large areas, rapidly, reliably and economically, thereby facilitating decision-making with respect to soil management and conservation.
- High earthworm population was observed under the Quesungual slash and mulch agroforestry system of South-Western Honduras and it was mostly localized near trees. In contrast, ant populations were not associated with the spatial distribution of trees and distributed in the rest of

the area. Earthworms were the most commonly nominated type of soil invertebrate, and were generally regarded as an organism that was beneficial to farm activities.

- Showed that the agropastoral treatments under no-till, as compared with the same treatments under minimum till system, had created soil conditions that are adequate for implementation of the no-till system on the Colombian savanna Oxisols.
- In the long-term crop rotation and ley farming systems experiment (CULTICORE) in the Colombian savannas it was shown that in highly weathered and P-deficient tropical soils, P availability for plant growth may depend more on biologically mediated organic P turnover processes than on the release of adsorbed inorganic P.
- Found that the nitrification inhibition activity of sexual accessions of *B. humidicola* was similar to the commercial apomictic cultivar indicating the possibility for genetic regulation of the trait.
- Showed that the use of bio-char in acid soils of very low natural fertility could increase crop and plant yield and could serve as a valuable tool to increase soil quality of infertile acid soils.
- During the past 2 years, implemented conservation farming practices (minimum tillage, green manures and direct drilling) on an area of about 1000 ha in the Fuquene watershed in Colombia and developed a financial mechanism with National Fund for Financing Farming in Colombia and showed that specific strategic alliances are required for benefiting the poorest farmers with new technologies.

Output target 2006

- ***Impact of three contrasting cropping systems on productivity and nutrient dynamics in hillsides and savannas quantified***

Published work0

D. Diouf, R. Duponnois, A. T. Ba, M. Neyra and D. Lesueur (2005) Symbiosis of *Acacia auriculiformis* and *Acacia mangium* with mycorrhizal fungi and *Bradyrhizobium* spp. improves salt tolerance in greenhouse conditions. Functional Plant Biology 32: 1143-1152
[1]UCAD, Senegal; [2]IRD, Burkina Faso;[1] UCAD Senegal; [3] IRD, Senegal;[4] TSBF-CIAT,Nairobi, Kenya
Abstract: The aim of our work was to assess the growth and mineral nutrition of salt stressed *Acacia auriculiformis* A. Cunn. ex Benth. and *Acacia mangium* Willd. seedlings inoculated with a combination of selected microsymbionts (bradyrhizobia and mycorrhizal fungi). Plants were grown in greenhouse conditions in non-sterile soil, irrigated with a saline nutrient solution (0, 50 and 100 mM NaCl). The inoculation combinations consisted of the *Bradyrhizobium* strain Aust 13c for *A. mangium* and Aust 11c for *A. auriculiformis*, an arbuscular mycorrhizal fungus (*Glomus intraradices*, DAOM 181602) and an ectomycorrhizal fungus (*Pisolithus albus*, strain COI 007). The inoculation treatments were designed to identify the symbionts that might improve the salt tolerance of both *Acacia* species. The main effect of salinity was reduced tree growth in both acacias. However, it appeared that, compared with controls, both rhizobial and mycorrhizal inoculation improved the growth of the salt-stressed plants, while inoculation with the ectomycorrhizal fungus strain appeared to have a small effect on their growth and mineral nutrition levels. Endomycorrhizal inoculation combined with rhizobial inoculation usually gave good results. Analysis of foliar proline accumulation confirmed that dual inoculation gave the trees better tolerance to salt stress and suggested that the use of this dual inoculum might be beneficial for inoculation of both *Acacia* species in soils with moderate salt constraints.

A.O. Esilaba[1], P. Nyende[3], G. Nalukenge[1], J. Byalebeka[2], R.J. Delve[1,3] and H. Ssali[2] (2005) Resource flows and nutrient balances in smallholder farming systems in Mayuge District, Eastern Uganda. Agriculture, Ecosystems and Environment 109: 192-201
[1]CIAT, Kampala, Uganda; [2]Kawanda Agricultural Research Institute, Kampala, Uganda; [3]TSBF-CIAT, Nairobi, Kenya
Abstract: Resource flow models are useful tools that assist farmers in analyzing their soil fertility management strategies and in planning, experimenting and adapting ways to improve the use of scarce local resources. Resource flows and farm nutrient balance studies were carried out in eastern Uganda to ascertain the movement of organic resources and nutrients in and out of the farm system during a participatory learning and action research (PLAR) process. The resource flows were transformed into nutrient flows and partial nutrient balances were calculated using the Resource Kit computer package. Results of a farmers' soil fertility management classification at the start of the PLAR intervention in 1999 revealed that 3% of the farmers were good soil fertility managers (class I), 10% were average soil fertility managers (class II) and 87% were poor soil fertility managers (class III). The results indicate that the net farm nutrient balances in kg ha^{-1} per season for all the nutrients [nitrogen (N), phosphorus (P), and potassium (K)] were negative for both the good and the poor soil fertility managers. Class I farm balances irrespective of the season, were however more negative than those of class III farms. For the long rains seasons (LR 2000, 2001 and 2002), the average net farm nutrient balances for N, P, and K for class I farms were 5.0, 0.6 and 8.0 kg ha^{-1} yr^{-1}, while for the short rains seasons (SR 2000 and 2001), the nutrient balances were 3.5, 0.5 and 6.0 kg ha^{-1} yr^{-1}, respectively. For the class III farms, the average net farm nutrient balances for N, P, and K in the long rain seasons (LR 2000, 2001 and 2002) were 3.3, 0.3 and 4.0 kg ha^{-1} yr^{-1} while for the short rains seasons (SR 2000 and 2001), the nutrient balances were 3.5, 0.5 and 5.0 kg ha^{-1} yr^{-1}, respectively. Soil management interventions for these small-scale farmers should aim at

reversing nutrient depletion with a focus on profitable management of the crop production system, which is the major cause of nutrient depletion.

A.O. Esilaba[1], J.B. Byalebeka[2], R.J. Delve[1,3], J.R. Okalebo[4], D. Ssenyange[5], M. Mbalule[6] and H. Ssali[2] (2005) On-farm testing of integrated nutrient management strategies in Eastern Uganda. Agricultural Systems 86: 144-165.
[1]CIAT, Kampala, Uganda, [2]Kawanda Agricultural Research Institute, Kampala, Uganda, [3]TSBF-CIAT, Nairobi, Kenya, [4]Moi University, Eldoret, Kenya, [5]Africa 2000 Network, Iganga, Uganda, [6]Forestry Resources Research Institute, Kampala, Uganda
Abstract: This paper reports on a Participatory Learning and Action Research (PLAR) process that was initiated in three villages in eastern Uganda in September 1999 to enable small-scale farmers to reverse nutrient depletion of their soils profitably by increasing their capacity to develop, adapt and use integrated natural resource management strategies. The PLAR process was also used to improve the participatory skills and tools of research and extension personnel to support this process. The farming systems of the area were characterized for socio-economic and biophysical conditions that included social organizations, wealth categories, gender, crop, soil, agro forestry and livestock production. Farmers identified soil fertility constraints, their indicators, and causes of soil fertility decline, and suggested strategies to address the problem of soil fertility decline. Soil fertility management diversity among households indicated that most farmers were not carrying out any improved soil fertility management practices, despite previous research and dissemination in the area. Following the diagnosis stage and exposure visits.

A. Mando[1], B. Ouattara[2], M. Sédogo[2], L. Stroosnijder[3], K. Ouattara[2], L. Brussaard[3] and B. Vanlauwe[4] (2005) Long-term effect of tillage and manure application on soil organic fractions and crop performance under Sudano-Sahelian conditions. Soil & Tillage Research 80: 95-101.
[1]IFDC, Togo; [2]INRAB, Burkina Faso; [3]Wageningen University, Netherlands; [4]TSBF-CIAT, Nairobi, Kenya
Abstract: Human-induced degradation of natural resources in general and of soil in particular, is a major problem in many regions, including the Sudano-Sahelian zone. The combined effects of tillage and manure application on Lixisol properties and on crop performance were investigated at Saria, Burkina Faso, to find efficient soil management practices to improve soil fertility. A randomized block design with four treatments (hand hoeing only, hand hoeing + manure, ploughing only, oxen ploughing + manure) in three replications was started in 1990. Ten years later, total soil organic (SOC), particulate organic matter and C mineralization were measured. Initial SOC concentration was 4 mg/g and dropped to 2.1 mg g^{-1} soil in ploughed plots without manure and to 2.5 mg g^{-1} soil in hoed plots without manure. Manure addition mitigated the decrease of SOC in ploughed plots and even built up SOC in hoed plots, where it increased to 5.8 mg g^{-1} soil. Manure had a large effect on the fractions in which SOC was stored. In ploughed plots, a large amount of SOC was stored in physical particles >0.25 mm, while in hand hoed plots the maximum SOC was stored in finer fractions. In the topsoil, hoeing and manure resulted in a higher SOC than ploughing with no manure. However, in the 15–25 cm layer, particularly in September, particulate organic matter was greater in ploughed plots with manure than in hoed plots with manure. Crop yields were highest on ploughed + manure plots and lowest on ploughed plots with no manure. We conclude that applying manure annually mitigates the negative effect of ploughing and hand hoeing on SOC and related properties and therefore can contribute to the sustainability of the agricultural system in the Sudano-Sahelian zone.

A. Sarr, M. Neyra, M. A. Houeibib, I. Ndoye, A. Oihabi and D. Lesueur (2005) Rhizobial populations in soils from natural *Acacia senegal* and *Acacia nilotica* forests in Mauritania and the Senegal River Valley. Microbial Ecology 50:152-162.
[1]University Marrakech, Morocco; [2]IRD, Senegal;[3] FST Nouakchott, Mauritania;[4] UCAD-Senegal; [5]TSBF-CIAT, Nairobi, Kenya

Abstract: Eighty-two strains of rhizobia were isolated from soils taken from several sites in Mauritania and Senegal. These soil samples were collected from natural stands of *Acacia nilotica* and *Acacia senegal*. The soils from Mauritania were less rich in native rhizobia than the soils from Senegal. The strains were characterized using PCR-RFLP and by sequencing the rDNA 16S-23S intergenic spacer region (IGS). They were sorted into 7 IGS groups. These groups were not associated with the geographical origin of the strains or with the host-plant species at the site where the soils were collected. Most of the strains were in three of the IGS groups (I, IV and V). One representative strain from each IGS group was sequenced and showed that the strains were from the genus *Mesorhizobium*. IGS groups I, IV and VI were close to the species *M. plurifarium* (AF345263), IGS groups II and III were close to the species *Mesorhizobium* sp. (AF510360), IGS groups V were close to the species *Mesorhizobium* sp. (AF510366) and VII to *Mesorhizobium* sp. (AF510346).

B. Vanlauwe[1], K. Aihou[2], B.K. Tossah[3], J. Diels[4], N. Sanginga[1] and R. Merckx[5] (2005) *Senna siamea* trees recycle Ca from a Ca-rich subsoil and increase the topsoil pH in agroforestry systems in theWest African derived savanna zone. Plant and Soil 269: 285-296.

[1]TSBF-CIAT ,Nairobi, Kenya, [2]INRAB, Benin, [3]ITRA, Togo, [4]IITA, Nigeria, [5]KULeuven, Belgium

Abstract: The functioning of trees as a safety-net for capturing nutrients leached beyond the reach of crop roots was evaluated by investigating changes in exchangeable cations (Ca, Mg, and K) and pH in a wide range of medium to long term alley cropping trials in the derived savanna of West Africa, compared to no-tree control plots. Topsoil Ca content, effective cation exchange capacity, and pH were substantially higher under *Senna siamea* than under *Leucaena leucocephala*, *Gliricidia sepium*, or the no-tree control plots in sites with a Bt horizon rich in exchangeable Ca. This was shown to be largely related to the recovery of Ca from the subsoil under *Senna* trees. The increase of the Ca content of the topsoil under *Senna* relative to the no-tree control treatment was related to the total amount of dry matter applied since trial establishment. The lack of increase in Ca accumulation under the other species was related to potential recovery of Ca from the topsoil itself and/or substantial Ca leaching. The accumulation of Ca in the topsoil under *Senna* had a marked effect on the topsoil pH, the latter increasing significantly compared with the *Leucaena*, *Gliricidia*, and no-tree control treatments. In conclusion, the current work shows that the functioning of the often hypothesized 'safety-net' of trees in a cropping system depends on (i) the tree species and on (ii) the presence of a subsoil of suitable quality, i.e., clay enriched and with high Ca saturation.

B. Vanlauwe[1], J. Diels[2], N. Sanginga[1] and R. Merckx[3] (2005) Long-term integrated soil fertility management in South-western Nigeria: Crop performance and impact on the soil fertility status. Plant and Soil 273: 337-354.

[1]TSBF-CIAT, Nairobi, Kenya; [2]IITA, Nigeria, Benin; [3]KULeuven, Belgium

Abstract: Crop response, tree biomass production and changes in soil fertility characteristics were monitored in a long-term (1986–2002) alley-cropping trial in Ibadan, Nigeria. The systems included two alley cropping systems with Leucaena leucocephala and Senna siamea on the one hand and a control (no-trees) system on the other hand, all cropped annually with a maize–cowpea rotation. All systems had a plus and minus fertilizer treatment. Over the years, the annual biomass return through tree prunings declined steadily, but more drastically for Leucaena than for Senna. In 2002, the nitrogen contribution from Leucaena residues stabilized at about 200 kg N ha^{-1} yr^{-1}, while the corresponding value for Senna was about 160 kg N ha^{-1} yr^{-1}. On average, the four Leucaena prunings were more equal in biomass as well as in amounts of N, P and cations, while the first Senna pruning was always contributing up to 60% of the annual biomass or nutrient return. Maize crop yields declined steadily in all treatments, but the least so in the Senna + fertilizer treatment where in 2002 still 2.2 Mg ha^{-1} of maize were obtained. Nitrogen fertilizer use efficiency was usually higher in the Senna treatment compared to the control or the Leucaena treatment. Added benefits due to the combined use of fertilizer N and organic matter additions were observed only for the Senna treatment and only in the last 6 years. At all other times, they remained absent or were even negative in the Leucaena treatments for the first 3 years. Most chemical soil fertility

parameters decreased in all the treatments, but less so in the alley cropping systems. The presence of trees had a positive effect on remaining carbon stocks, while they were reduced compared to the 1986 data. Trees had a positive effect on the maintenance of exchangeable cations in the top soil. Exchangeable Ca, Mg and K – and hence ECEC – were only slightly reduced after 16 years of cropping in the tree-based systems, and even increased in the Senna treatments. In the control treatments, values for all these parameters reduced to 50% or less of the original values after 16 years. All the above points to the Senna-based alley system with fertilizers as the more resilient one. This is reflected in all soil fertility parameters, in added benefits due to the combined use of fertilizer nitrogen and organic residue application and in a more stable maize yield over the years, averaging 2.8 Mg ha^{-1} with maximal deviations from the average not exceeding 21%.

E. Barrios[1], J.G. Cobo[1], I.M. Rao[1], R.J. Thomas[1,2], E. Amézquita[1], J.J. Jiménez[1,3],and M.A. Rondón[1] (2005) Fallow management for soil fertility recovery in tropical Andean agroecosystems in Colombia. Agriculture, Ecosystems and Environment 100: 29-42.

[1]TSBF-CIAT, Cali, Colombia; [2] ICARDA Syria; [3]Ohio State University, USA

Abstract: Andean hillsides dominate the landscape of a considerable proportion of Cauca Department in Colombia. The typical cropping cycle in the region includes monocrops or intercrops of maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.) and/or cassava (*Manihot esculenta* Crantz). Cassava is usually the last crop before local farmers leave plots to natural fallow until soil fertility is recovered and a new cropping phase can be initiated. Previous studies on land use in the Río Cabuyal watershed (6500 ha) show that a considerable proportion of land (about 25-30%) remains under natural fallow every year. The focus of our studies is on systems of accelerated regeneration of soil fertility, or improved fallow systems, as an alternative to the natural regeneration by the native flora. Fallow improvement studies were conducted on plots following cassava cultivation. The potential for soil fertility recovery after 12 and 28 months was evaluated with two fast growing trees, *Calliandra calothyrsus* Meissn (CAL) and *Indigofera constricta* L.(IND), and one shrub, *Tithonia diversifolia* (Hemsl.) Gray (TTH), as slash/mulch fallow systems compared to the natural fallow (NAT). All planted slash/mulch fallow systems produced greater biomass than the natural fallow. Greatest dry biomass (16.4 Mg ha^{-1} yr^{-1}) was produced by TTH. Other planted fallows (CAL and IND) produced about 40% less biomass than TTH and the control (NAT) about 75% less. Nutrient levels in the biomass were especially high for TTH, followed by IND, CAL, and NAT. The impact of fallow management on soil chemical, physical and biological parameters related to residual soil fertility during the cropping phase was evaluated. Soil parameters most affected by slash/mulch fallow systems included soil total N, available N (ammonium and nitrate), exchangeable cations (K, Ca, Mg and Al), amount of P in light fraction, soil bulk density and air permeability, and soil macrofauna diversity. Results from field studies suggest that the *Tithonia* slash/mulch fallow system could be the best option to regenerate soil fertility of degraded volcanic-ash soils of the Andean hillsides.

Completed work

Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe

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An improved understanding of soil fertility variability and farmers' resource use strategies is required for targeting soil fertility improving technologies to different niches within farms. We measured the variability of soil fertility with distance from homesteads on smallholder farms of different socio-economic groups on two soil types, a granite sand and a red clay, in Murewa, northeast Zimbabwe. Soil organic matter, available P and CEC decreased with distance from homestead on most farms. Available P was most responsive to management, irrespective of soil type, as it was more concentrated on the plots closest to homesteads on wealthy farms (8 to 13 mg kg^{-1}), compared with plots further from homesteads and all plots on poor farms (2-6 mg kg^{-1}). There was a large gap in amounts of mineral fertilizers used by the wealthiest farmers (>100 kg N and 15 kg P per farm) and the poorest farmers (<20 kg N and <10 kg P per farm). The wealthy farmers who owned cattle also used large amounts of manure, which provided at least 90 kg N and 25 kg P per farm. The poor farmers used little or no organic sources of nutrients. The wealthiest farmers distributed mineral fertilizers evenly across their farms, but preferentially targeted manure to the plots closest to the homesteads, which received about 70 kg N and 25 kg P per plot from manure compared with 20 kg N and 8 kg P per plot on the mid-fields, and 10 kg N and 2 kg P per plot on the outfields. All the farmers invariably applied nutrients to maize but little to groundnut. Maize grain yields were largest on the homefields on the wealthy farms (2.7 to 5.0 Mg ha^{-1}), but poor across all fields on the poor farms (0.3 to 1.9 t ha^{-1}). Groundnut grain yields showed little difference between farms and plots. N and P partial balances were largest on the wealthy farms, although these fluctuated from season to season (–20 to +80 kg N per farm and 15 to 30 kg P per farm). The partial balances on the wealthy farms were largest on the homefield (20 to 30 kg N and 13 kg P per plot), but decreased to 10 to 20 N and 6 to 9 kg P per plot in midfields and –7 to +10 kg N and –1 to +1 kg P per plot in the outfields. N and P balances differed little across plots on the poor farms (–5 to +5 kg per plot) due to limited nutrients applied and small off-take from small harvests. Full N and P balances were negative for most farms and plots due to large nutrient losses estimated for soil erosion (12 to 30 kg N ha^{-1} and 6 to 15 kg P ha^{-1}), leaching (21 to 26 kg N ha^{-1}) and denitrification (3 to 16 kg N ha^{-1}). This study highlights the need to consider soil fertility gradients and the nutrient management patterns creating them when designing options to improve resource use efficiency on smallholder farms.

Soil type, historical management and current resource allocation: three dimensions regulating variability of maize yields and nutrient use efficiencies on smallholder farms

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Soil fertility varies strongly between different fields within and between farms as a consequence of inherent and management factors, that have major implications for crop production and nutrient use efficiencies. We conducted experiments for three years (seasons) that assessed maize yields following application of 100 kg N ha^{-1} with different rates of P (0, 30, 50 kg ha^{-1}) from two sources (single super phosphate and cattle manure) on homefields and outfields on a granitic sandy soil and a red clay soil. For three seasons, maize yields on control plots were larger on the homefields than outfields for both soil types. For the different field types yields were larger in the order: homefield clay (1.5-2.1 Mg ha^{-1}) > homefield sand (0.8-1.0 Mg ha^{-1}) ~ outfield clay (0.6-0.8 Mg ha^{-1}) > outfield sand (0.1-0.3 Mg ha^{-1}). The differences in yields are attributed to the fertility status of the fields due to past application of manure. Soil organic matter, available P, and exchangeable bases were higher on the homefields than outfields, due to farmers' preferential allocation of nutrient resources on fields closest to homesteads. Application of mineral N significantly increased maize yields on homefields in the first season: to 3.1 Mg ha^{-1} on the clay soil and 1.5 Mg ha^{-1} on the sandy soil. Effects of N alone were insignificant on the outfields due to other limiting factors. Greatest yields of about 6 Mg ha^{-1} were achieved on the homefield on clay soil with 100 kg N ha^{-1} and 30 P kg ha^{-1} (SSP). Manure gave larger yields (3-4 Mg ha^{-1}) than SSP (2-3 Mg ha^{-1}) on the homefield on sandy soil and outfield on clay soil. Maize did not respond significantly to N, dolomitic lime and P (both manure and SSP) on the depleted outfield on sandy soil in the first and second seasons. Only in the third season of application of manure (> 30 P kg ha^{-1}, about 20 Mg ha^{-1}) was a significant response in grain yields observed. Large amounts of manure are therefore required for several seasons to restore the fertility of depleted outfields on the sandy soils. N recovery efficiencies without P applied were in the order: sand homefield (20%) > clay homefield (16%) > clay homefield (8%) > sand outfield (5%). Application of SSP and manure significantly increased apparent N recovery efficiencies to about 98% and 97% (clay homefield), 40% and 60% (sand homefield and clay outfield) and 12% and 18% (sand outfield). Measurement of grain yields at different rates of N application revealed that about 6 t ha^{-1} can be achieved at high application N rates (up to 120 kg N ha^{-1}) on the homefield on clay soil, with P applied. Maximum yields of about 3 Mg ha^{-1} were attained on the homefield on sandy soil and outfield on

clay soil with less than 60 kg N ha^{-1}. Maize responses to N, SSP, manure and dolomitic lime and attainable yields varied strongly on different fields. A three dimensional perspective to soil fertility management encompassing (i) soil type, (ii) past management of fields and (iii) targeted application of mineral fertilizers and manure is imperative for improving nutrient use efficiencies on smallholder farms.

Multiple effects of manure: a key to maintenance of soil fertility and restoration of depleted sandy soils on smallholder farms

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Manure is a key nutrient resource on smallholder farms in the tropics, especially on poorly buffered sandy soils, due to its multiple benefits for soil fertility. Soil chemical parameters on farmers' fields with different histories of cattle manure application on a sandy soil and a clay soil were measured to assess the long-term effects of manure use. Changes in soil properties were assessed following three years of inorganic N fertilizer application, with manure or mineral P, on fields with different initial fertility. Limiting nutrients and the capacity of manure to supply N, P, bases and micronutrients were also tested in greenhouse pot experiments using maize (*Zea mays* L.). The homefields where farmers concentrated manure and fertilizers were more fertile than outfields which received few inputs. The chemical properties on the homefields on sandy and clay soils respectively were: 0.5% and 1.4% C; 0.04% and 0.08% N; 5.1 and 5.6 pH(H_2O); 7.2 and 12.1 mg kg^{-1} available P; 2.2 and 24.2 $cmol_c$ kg^{-1} CEC; 73% and 78% base saturation, and properties for the outfields: 0.3% and 0.7% C; 0.03% and 0.05% N; 4.9 and 5.4 pH(H_2O); 2.4 and 3.9 mg kg^{-1} available P; 1.6 and 22.0 $cmol_c$ kg^{-1} CEC; and 37 and 69% base saturation. Addition of about 17 t ha^{-1} manure in combination with ammonium nitrate (100 kg N ha^{-1}) for three seasons significantly increased soil organic matter by up to 63%, pH by 0.2 units, available P by 8 (mg kg^{-1}) and base saturation by 20% on the outfield on sandy soil. Sole N as ammonium nitrate (100 kg N ha^{-1}) or in combination with SSP led to acidification of the sandy soils, with a decrease of up 0.8 pH units after three seasons. In the greenhouse experiment N and Ca were identified as deficient on the homefield of the sandy soil and N, P, Ca and Zn were deficient on the outfield. No nutrient deficiencies were detected on the homefield on clay soil, whilst P was deficient on the outfield on clay soil. Manure alleviated the deficiencies of Ca and Zn on the sandy soil in the greenhouse. This study highlights the essential role of manure in sustaining and replenishing soil fertility on smallholder farms through its multiple effects. Manure may not supply sufficient N and required by crops, whilst mineral N and P fertilizers alone do not supply other essential nutrients and may acidify the soil. Integrated use of mineral N and P fertilizers and manure is therefore required for sustainable crop production and soil fertility management.

Soil organic carbon dynamics, functions and management in West African agro-ecosystems

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Soil fertility depletion (mainly N, P and carbon) has been described as the single most important constraint to food security in West Africa. Over half of the African population is rural and directly dependent on locally grown crops. Further, 28% of the population is chronically hungry and over half of people are living on less than US$ 1 per day as a result of soil fertility depletion.

Soil organic carbon (SOC) is simultaneously a source and sink for nutrients and plays a vital role in soil fertility maintenance. In most parts of West Africa agro-ecosystems (except the forest zone), the soils are inherently low in SOC. The low SOC content is due to the low shoot and root growth of crops and natural vegetation, the rapid turnover rates of organic material as a result of high soil temperatures and fauna activity particularly termites and the low soil clay content. With kaolinite as the main clay type, the cation exchange capacity of the soils in this region, often less that 1 $cmol_c$ kg^{-1}, depends heavily on the SOC. There is a rapid decline of SOC levels with continuous cultivation. For the sandy soils, average annual losses may be as high as 4.7% whereas with sandy loam soils, losses are lower, with an average of 2%. To

maintain food production for a rapidly growing population application of mineral fertilizers and the effective recycling of organic amendments such as crop residues and manures are essential.

Crop residue application as surface mulch can play an important role in the maintenance of SOC levels and productivity through increasing recycling of mineral nutrients, increasing fertilizer use efficiency, and improving soil physical and chemical properties and decreasing soil erosion. However, organic materials available for mulching are scarce due to a low overall production levels of biomass in the region as well as their competitive use as fodder, construction material and cooking fuel. Animal manure has similar role as residue mulching for the maintenance of soil productivity but it will require between 10 and 40 ha of dry season grazing and between 3 and 10 ha of rangeland of wet season grazing to maintain yields on one hectare of cropland. The potential of manure to maintain SOC levels and maintain crop production is thus limited by the number of animals and the size and quality of the rangeland. The potential livestock transfer of nutrients in West Africa is 2.5 kg N and 0.6 kg P per hectare of cropland.

Scarcity of organic matter calls for alternative options to increase its availability for improvement of SOC stock. Firstly, the application of mineral fertilizer is a prerequisite for more crop residues at the farm level and the maintenance of soil organic carbon in West African agro-ecosystems and therefore most research should focus on the improvement of nutrient use efficiency in order to offer to the smallholder farmers cost-effective mineral fertilizer recommendations. Secondly, recent success story on increasing crop production and SOC at the farm level is the use of the dual purpose grain legumes having ability to derive a large proportion of their N from biological N fixation, a low N harvest and substantial production of both grain and biomass. Legume residues can be used for improvement of soil organic carbon through litter fall, or for feeding livestock with the resultant manure being returned to the crop fields.

In the decision support system for organic matter management, recommendations for appropriate use of organic material was made based on their resource quality, expressed as a function of N, polyphenol and lignin content. High quality organic materials release a high proportion of their N quickly. The impact of organic resource quality on SOC is less clear. Low quality organic resources contain substantial amounts of soluble polyphenols and lignins that may affect the longer-term decomposition dynamics and contribute to the build up of SOC. Future research needs to focus more on whether the organic resource quality concept is also useful for predicting different degrees of stabilization of applied organic C in one or more of the organic matter pools.

Differences in rooting strategies of planted fallows in volcanic-ash soils of hillsides

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In the mid-altitude hillsides of the Colombian Andes, agriculture is typically based on fallow/rotation systems in which forest or bush fallow is cleared for cropping with annuals or perennials. One alternative for poor farmers is to manage short-term fallow systems with planted herbaceous or woody legumes ("improved fallows") that replenish soil nutrient stocks faster than plants in natural succession. These short-term planted fallows can restore soil fertility in soils with limited nitrogen (N) and/or phosphorus (P) by enhancing nutrient recycling through the provision of soil organic matter (SOM).

We used a slash/mulch system with spatial design features of an agroforestry planted fallow system but involves pruning where resulting biomass is applied to the same fallow plot. Our objective was to determine whether planted fallow systems under slash and mulch management would perform better than the predominant practice of natural fallow, which allows regeneration of secondary vegetation. In this study we evaluated root growth and distribution differences among planted fallow species (*Indigofera*, *Calliandra*, and *Tithonia*) under 'slash and mulch' management compared with the natural fallow system.

The study was conducted at two farms in Pescador, located in the Andean hillsides of the Cauca Department, southwestern Colombia (2º48' N, 76º33' W) at about 1500 m above sea level. Planted fallow experiments were established at two farm locations on degraded soils previously cultivated with cassava for three years, corresponding to the typical end of cropping cycle when soils are left to natural fallow. The BM1 experiment was established at San Isidro Farm in Pescador as a random complete block (RCB) design with four system treatments and three field replications. Planted fallow system treatments included two tree legumes, *Calliandra calothyrsus* Meissn.(CIAT 20400) (CAL) and *Indigofera constricta* Rydb. (IND) and one shrub *Tithonia diversifolia* (Hems.) Gray (TTH) from the Asteraceae family, compared to a natural fallow system (NAT). Experiment BM2 was established at the Benizio Velazco Farm also in Pescador. It was also established as a RCB design but due to limited space it consisted of three treatments with three field replications. IND and CAL were pruned to 1.5 m height at 18 months after planting and weighed biomass was laid down on the soil surface. In TTH plants were pruned to 20 cm for a total of six times, starting eight months after planting and weighed biomass laid on the soil surface.

Whole plot measurement of biomass production during each pruning event (by plant part) was carried out and a composite sub-sample taken for laboratory analyses before laying down the pruned biomass on the soil surface. All above ground biomass was harvested after 27 months with the conclusion of the fallow phase, weighed, sub sampled and laid on the soil surface. Firewood biomass (stems and large branches) was removed from the field and weighed, while leaving leaves, sexual structures (flowers&pods) and small branches on the soil surface. Whole plot measurements of biomass production in NAT was only conducted once at the end of the fallow period (27 months) when all existing natural re-growth vegetation was slashed and sub-samples for analysis taken prior to applying the biomass on the soil surface.

After 14 months of plant growth, a sample area of 1 m^2 was randomly selected within each plot and all the above ground biomass in this area was harvested. The biomass from the rest of the plot was harvested for the total biomass determination. The biomass from the sample area was separated into leaves, stems and the reproductive structures (flowers and seeds). Root distribution was determined using soil coring method. Soil samples were collected from 12 core samples taken with a 5 cm diameter manual auger into each area used for sampling of shoot biomass. Coarse and fine roots were separated from the soil by washing out the roots on a 1 mm sieve for each soil layer (0-5, 5-10, 10-20 and 20-40 cm). After washing out the roots on a 1 mm sieve, the "live" roots were hand separated from organic material. Root length was measured with the Comair Root Length Scanner and expressed in km of root length per m^2 of ground area. Root biomass was determined after drying the samples in an oven at 70 °C for 2 days. The specific root length was calculated in m of root length per g of dried roots. All statistical analyses were performed using SAS.

Increase in age of the planted fallow plants increased shoot biomass production at both farms of BM1 and BM2 (Table 1). Calliandra was more productive on the less fertile BM2 farm than on the fertile BM1 farm. Indigofera was more productive on the fertile BM1 farm. Calliandra had greater values of leaf area index than the other 2 species of planted fallows at 14 or 27 months after planting. Shoot biomass production of natural fallow at 14 months was similar to that of Calliandra and Tithonia at BM1 farm. At 27 months after establishment, live shoot biomass (leaf + stem) of Indigofera was greater at BM1 farm while Calliandra was greater at BM2 farm. Calliandra also had greater biomass of reproductive structures at 14 months after establishment.

Table 1. Leaf area index and shoot biomass components of three planted fallow species (*Calliandra calothyrsus* CIAT 20400, *Indigofera constricta* and *Tithonia diversifolia*) at two times after establishment compared with natural fallow at 2 farms (BM1 and BM2) in a hillsides agroecosystem of Pescador, Cauca, Colombia.

Fallow species	Age of the plant (months)	Leaf area index ($m^2 m^{-2}$)	Leaf biomass	Stem biomass	Reproductive structures biomass	Live shoot biomass	Dead shoot biomass	Shoot regrowth	Total shoot biomass
				------------------------------------	(Mg ha^{-1})	--------------------------------			
BM1									
CAL	14	2.53	4.24	6.12		10.36			10.36
IND	14	1.47	3.07	15.93	0.15	19.07			19.07
TTH	18	6.31	2.76	11.38	0.44	14.58	0.40	6.20	21.18
NAT	18	1.81	1.40	5.50		6.90	3.64		10.54
LSD($P<0.05$)		4.53	2.66	NS	NS	NS			NS
CAL	27	8.78	7.37	15.97		23.34			23.34
IND	27	4.11	2.96	26.38	0.10	29.44			29.44
TTH	27	14.14	5.68	7.12		12.81		26.81	39.62
NAT	27					11.48			11.48
LSD($P<0.05$)		7.60	2.68	11.36					18.10
BM2									
CAL	14	4.24	8.70	13.06	0.44	21.84			21.84
IND	14	0.87	1.95	12.61	0.04	14.58			14.58
NAT	18	0.83	0.63	2.42		3.05	2.37		5.42
LSD($P<0.05$)		1.08	1.64	NS		13.85			14.02
CAL	27	7.65	9.46	28.09		37.55			37.55
IND	27	3.17	2.49	19.22	0.03	21.73			21.73
NAT	27					6.12			6.12
LSD($P<0.05$)		3.70	3.57	NS		15.71			15.71

NS = not significant

Differences among planted fallows in root attributes and root to shoot relationships are shown in Table 2. Greater values of root length and lower values of root biomass indicate the fine root production. Differences among planted fallows in comparison with native fallow in distribution of fine root length across 0 to 40 cm soil depth are shown in Figure 1. Native fallow showed greater fine root production than planted fallows at both farms. Fine root production (fine root length) of planted fallows increased with the age of the plants in the fertile farm of BM1 but not on infertile farm BM2 (Figure 1). Coarse root length of Calliandra was also greater than that of Indigofera on the infertile BM2 farm. Corase root biomass values were markedly superior for Calliandra compared to other fallow species at both farms. As expected, the lowest values of coarse roots were observed with native fallow at both farms. Native fallow also showed markedly greater values of root length to shoot biomass than the planted fallows. Values of root biomass to shoot biomass ratio were also greater for Calliandra, particularly at the infertile BM2 site. This indicates the ability of Calliandra to adapt to infertile soil conditions by changing partitioning of biomass to root growth and development over time. The ability to produce greater amounts of fine roots by Calliandra, particularly at deeper soil layers (Figure 1) is an adaptive strategy to explore greater volume of soil for immobile nutrients such as P that is low in its availability in these volcanic-ash soils of Andean hillsides.

Table 2. Root length, root biomass and root to shoot relationships of three planted fallow species (*Calliandra calothyrsus* CIAT 20400, *Indigofera constricta* and *Tithonia diversifolia*) at two times after establishment compared with natural fallow at 2 farms (BM1 and BM2) in a hillsides agroecosystem of Pescador, Cauca, Colombia.

Fallow species	**Age of the plant (months)**	**Root length** ------------km m^{-2}--------			**Root biomass** -------------kg ha^{-1}------------			**Root length to shoot biomass ($m\ g^{-1}$)**	**Root biomass to shoot biomass ($g\ g^{-1}$)**
		Fine	**Coarse**	**Total**	**Fine**	**Coarse**	**Total**		
BM1									
CAL	14	2.20	0.07	2.26	517	1838	2355	2.41	0.26
IND	14	1.85	0.09	1.95	303	2554	2857	1.17	0.20
TTH	18	3.08	0.00	3.08	308	114	421	3.47	0.04
NAT	18	5.65	0.00	5.65	491	25	516	5.96	0.06
LSD($P<0.05$)		2.06	0.07	2.06	NS	NS	NS	3.61	NS
CAL	27	6.38	0.08	6.45	574	6275	6849	3.88	0.38
IND	27	5.49	0.03	5.52	428	1957	2386	2.09	0.09
TTH	27	4.19	0.01	4.21	199	521	721	1.95	0.04
NAT	27	11.38	0.02	11.40	1566	139	1705	9.05	0.14
LSD($P<0.05$)		NS	0.05	9.59	3947	3631	5586	5.59	0.27
BM2									
CAL	14	5.88	0.15	6.02	778	3972	4750	2.94	0.23
IND	14	4.50	0.05	4.55	600	535	1135	5.29	0.13
NAT	18	8.45	0.00	8.46	465	154	619	16.54	0.12
LSD($P<0.05$)		NS	0.10	NS	267	1554	1697	8.71	NS
CAL	27	6.20	0.13	6.34	497	15711	16208	1.93	0.49
IND	27	4.16	0.04	4.20	346	1162	1507	2.08	0.07
NAT	27	6.13	0.01	6.14	463	278	741	11.15	0.14
LSD($P<0.05$)		NS	0.10	NS	NS	8431	8757	2.66	0.32

NS = not significant

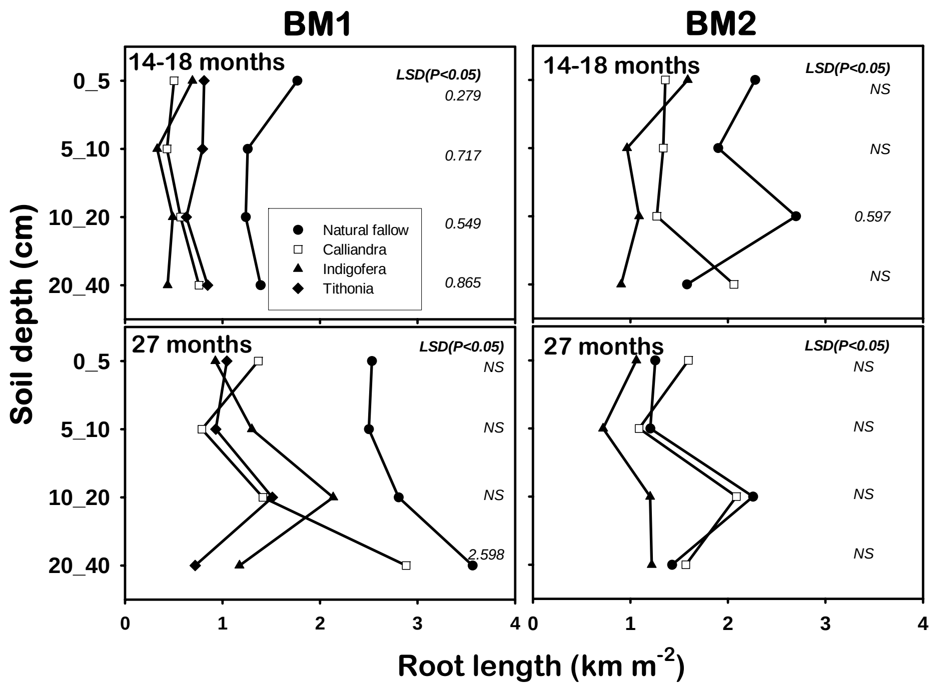

Figure 1. Distribution across soil depth (0-40 cm) of length of the fine roots of three planted fallow species (*Calliandra calothyrsus* CIAT 20400, *Indigofera constricta* and *Tithonia diversifolia*) at two times after establishment compared with natural fallow at 2 farms (BM1 and BM2) in a hillsides agroecosystem of Pescador, Cauca, Colombia.

Work in progress

Biophysical characterization of the Quesungual Agroforestry System

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The Quesungual agroforestry system (QSMAS) is an alternative to slash and burn management. It is based on planting annual crops (maize, sorghum, beans) and pastures under an indigenous slash and mulch management system. It combines the regrowth of native forest vegetation with no burning and zero tillage/direct planting operations on a permanent soil cover. More than 6,000 farmers covering an estimated area of 7,000 ha, who have adopted the QSMAS system during the last ten years in Honduras, have increased crop yields by more than 100% (maize from 1200 to 2500 kg ha^{-1}, beans from 325 to 800 kg ha^{-1}) in comparison with the traditional slash and burn system. More innovative farmers are intensifying and diversifying this system using vegetables and market-oriented cash crops as well as livestock.

In 2004, we obtained financial support from the Water and Food Challenge Program in order to determine the key management principles behind the social acceptance and biophysical resilience of QSMAS and its capacity to sustain crop production and alleviate water deficits on steeper slopes with high risk of soil erosion. One of the specific products of the project is the socio-economic and biophysical characterization of the system

The characterization study included the analysis of land cover, elevation and slope based on 1: 20,000 Digital Elevation Model (DEM) developed for the Southern Lempira region. This model was generated by combining topographic digital maps and Landsat Images from 2002. Rainfall data was obtained from the service of Meteorology of Honduras. The study was complemented with field visits to verify accuracy of de DEM.

Preliminary analysis of the information indicates that the management principles of the Quesungual (no burning, permanent cover of the soil and management of trees) are practiced over an area of 59,475 hectares (Figure 2). Seventy percent of this area lies within a range of 200- 800 masl and has slopes greater than 50%. The overall landscape is characterized by a mosaic of maize-based systems inserted within large areas of fallows after Quersungual. Mean annual rainfall varies from 1925 to 2218 mm depending on altitude. Most of the rain falls between the period May- November. The driest and hottest months are February and April, respectively while the wettest months are between June to September. Mean annual temperature varies between 16-21^0 C (minimum) and 28-34 ^{0} C (maximum).

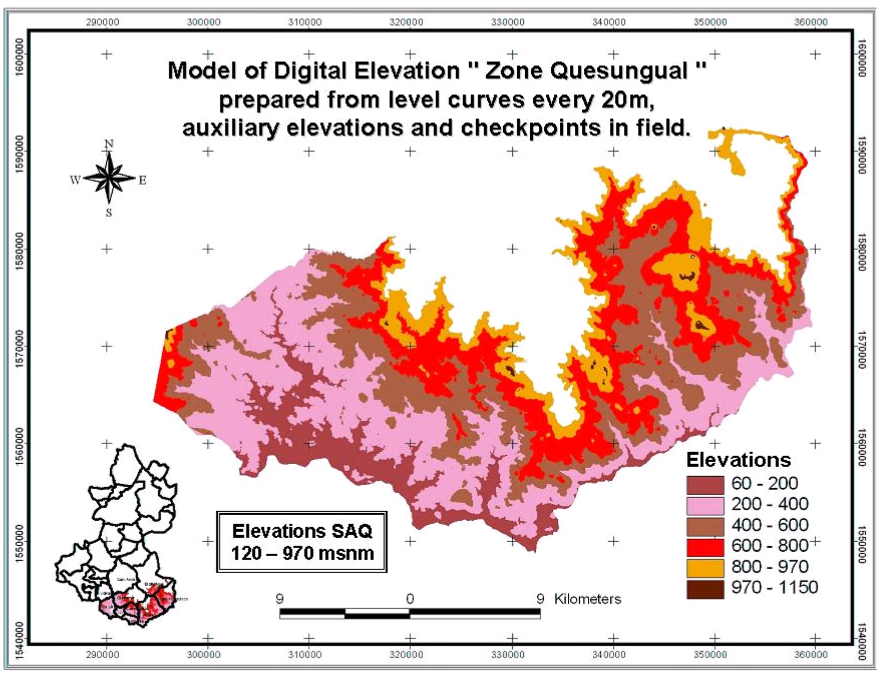

Figure 2. Map of the area of influence of the Quesungual system in the southern region of Lempira, Honduras using a digital elevation model.

The study examined how soil properties varied along several toposequences that included the on-farm plots used for the project with respect to modal profiles of two watersheds containing the on-farm plots (Figure 3). In the first phase of the study, the main soil units found at the watershed scale were identified using aerial photographs, secondary information and photo- interpretation. This information was verified and corrected in the field in a second phase of the work. Modal soil profiles were then described for each soil unit and samples were taken to the lab for analysis.

Main results indicate that the geology of the area is characterized by a massive presence of intrusive material developed during the tertiary. This material is comprised of fragmented rocks of diorites and grain-diorites of varying sizes underlying close to the soil surface in the upper part of the watersheds. Soil depth varies between 12 - 100 cm but most common depth is less than 40 cm. Dominant soil textures are sandy to clay loams and slopes are greater than 50%. Most common soil orders found along the toposequences were Entisols (upper parts), Inceptisols (medium parts) and Mollisols (lower parts).

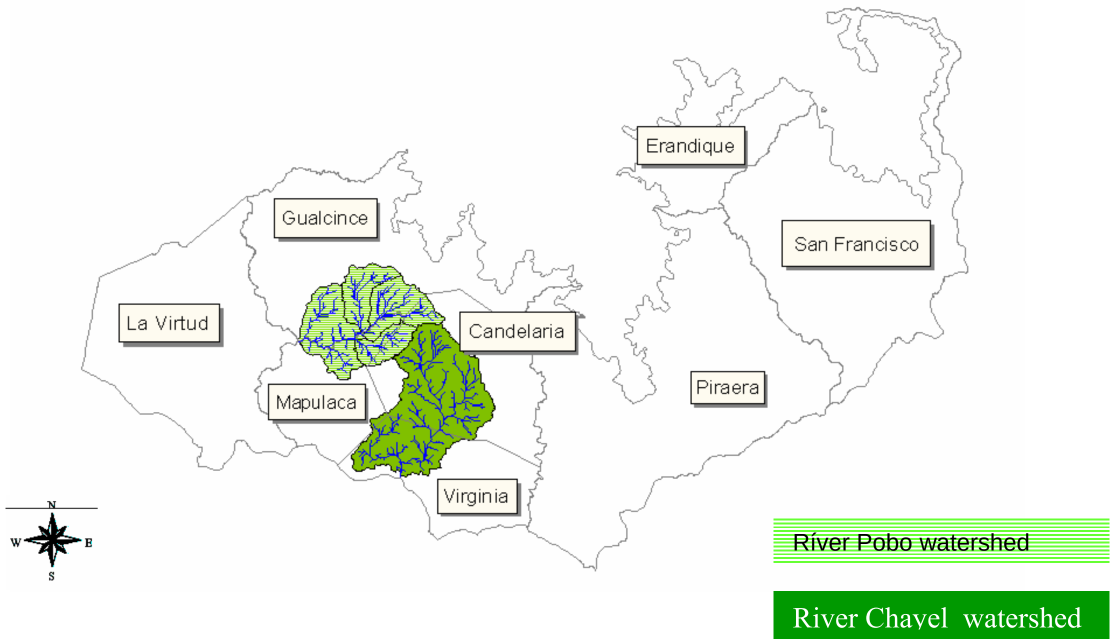

Figure 3. Location of the study area for the detailed soil characterization at toposequence and watershed levels.

Soil analyses are presented in Table 3. Results indicate that soil properties at the farm and watershed scales are similar. On the other hand they show clearly that these soils are acid and very deficient in P.

Table 3. Comparison between topsoil chemical properties of on-farm toposequences and the modal profiles of the watersheds Chayel and Pobo.

Soil Properties	**Sampling scale**			
	Farms (28 topsoil samples)		**Watershed (25 topsoil samples)**	
	Range	Mean	Range	Mean
pH	4.6- 6.2	5.0	5.0-6.4	5.5
SOM (%)	1.4-8.9	3.7	1.07-5.70	3.7
Total N (%)	0.1-0.4	0.2	0.05-0.29	0.2
P (ppm) Olsen	0.5-9.0	2.6	0.5-9.0	2.4
Ca (ppm)	420-4040	2612	320-3930	1709
K (ppm)	45-360	156	40-325	157
Mg (ppm)	51-557	406	16-1500	387
Zn (ppm)	0.3-2.2	0.7	0.26-0.42	0.3
Cu (ppm)	0.02-1.20	0.42	0.2-1.46	0.6
Fe (ppm)	4.0-58.0	27.4	10-90	29.3
Mn (ppm)	1.0-27.0	10.7	1.0-16.0	6.1

Response of maize-bean rotation to different rates of phosphorus fertilizer and chicken manure to a Colombian volcanic-ash soil

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High P fixation is common in soils with high volcanic ashes, and the crop response by farmers is generally sub-optimal in this kind of soils under continuous cultivation. To maximize P fertilizer use efficiency under these conditions, both from organic and inorganic amendments, it is necessary to be able to quantify the residual value of previous P fertilizer applications. To investigate this further, two experiments on Colombian volcanic ash-soils were designed: 1) RPRE, using triple super phosphate applied once only at the beginning of the experiment, or annually to the maize crop in a two-crops-per-year rotation; and 2) CHME, using chicken manure applied annually to the maize crop in the same two-crops-per-year rotation. The objectives of these experiments were: 1) to determine optimal levels of soluble phosphate fertilizer/chicken manure for maize and common bean on these soils; 2) to characterize the fate of P fertilizer and chicken manure applications (uptake by crop, removal in products, immobilization in organic matter, reversion to less soluble inorganic phases); 3) to determine the residual value of phosphate applications (only for RPRE experiment); and 4) generate data for future parameterization of simulation models - e.g. APSIM. In this paper we show the response of crops on plant biomass production and grain yield.

The experimental plots were located in Pescador, Cauca department, Colombia (2º48' N, 76º33' W, 1500 m.a.s.l.). Soils are derived from volcanic-ashes, presenting an allophone content of 14.5%, and have been classified previously as Andepts (Oxic Dystropepts); however, since 1999 Andepts are considered as Andisols. Figure 4 shows the climate conditions during experimental time. Both experiments were randomised complete block designs with four replicates. Plot size in both experiments was 7 m by 7 m. RPRE included nine treatments, corresponding to 9 levels of P fertilizer as triple super phosphate applied once only at the beginning of the experiment (20, 40, 80 and 160 kg P ha^{-1}) or annually (0, 5, 10, 20 and 40 kg P ha^{-1}) to the maize crop in a two-crops-per-year rotation. CHME included 4 treatments, corresponding to 4 levels of chicken manure (0, 3, 6 and 12 Mg ha^{-1}) applied annually to the maize crop in the same two-crops-per-year rotation. However, in the last maize cycle, the 5 kg P ha^{-1} treatment in RPRE was increased to 160 kg P ha^{-1} to compare with the residual treatment of 160 kg P ha^{-1}. Similarly, chicken manure was not applied in the 12 Mg ha^{-1} treatment of CHME for assessing residual effect. Fertilizer and manure were applied to soil by broadcasting.

Maize cv. Cresemillas, with a density of 50,000 plants ha^{-1}, was planted in September 2001 and dry bean cv. ICA Caucayá (PVA 773), with a density of 166,666 plants ha^{-1}, was planted in next March. This maize and bean rotation was continued through three more cycles using the same scheme (Figure 1). Basal nutrients (N, K, Ca, Mg, and micronutrients) were applied to both crops and to all treatments in RPRE but not in CHME. Maize was harvested between February-March of 2002 till 2005, while beans were harvested between June-July of 2002 till 2005 (Figure 4). In each harvest, crop plant parts and weeds were separately weighed and sampled for laboratory analysis (data not shown). Maize and bean yields were expressed as grain weight (means±stderr) at 12.5% and 14% of water content, respectively.

In general, maize and bean biomass and yields in both RPRE and CHME responded proportionally to the gradual applications of P. In RPRE at the first cycle, for example, the control (0) and 160R had the lowest and greatest values, respectively (Figure 5). The same was observed in CHME, where control (0M) obtained the lowest values while 12M obtained the greatest. These results confirmed the hypothesis that these soils, by it self, can not sustain crop production due to their low P availability and high P fixation, and therefore high or continuous P additions (combined with adapted cultivars to low-P conditions) should be employed.

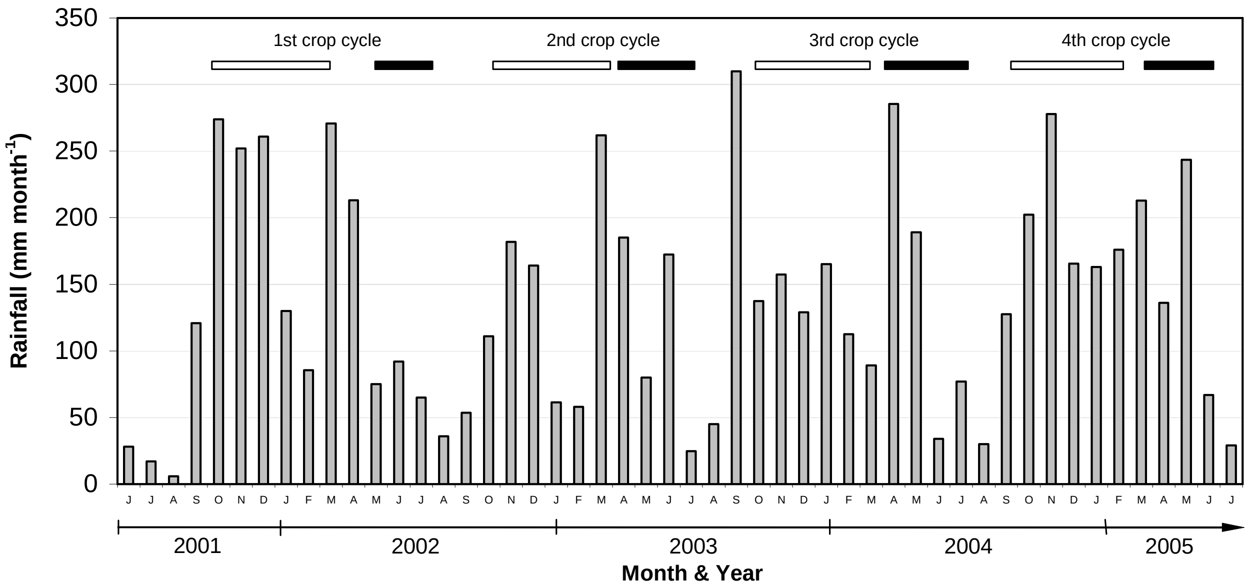

Figure 4. Monthly rainfall (shadow area) in Pescador (Cauca, Colombia) during experimental time. Horizontal bars refer to cropping cycles (□ maize ■ beans).

Maize biomass and yields in the 2nd cycle were generally the lowest among all cycles, especially in RPRE. Since diseases and insects were not a major problem in different seasons of maize, this was attributed to inadequate rainfall. In fact, there was a very low rainfall (~ 60 mm/month) in January-February 2003, which coincided with the stages of flowering and grain filling, respectively (see Figure 4). Diseases (e.g. Anthracnose and Mustia), on the contrary, did affect severely beans, mainly in RPRE in the 2nd and 3rd cycles (Figure 5). Actually, either the crop totally failed or produced insignificant yields in most of the treatments (only 40A and 160R had some production). Apparently, greater P availability due to greater P applications induced bean plants to recover from diseases (more quickly or more effectively) and therefore they could yield at a greater level.

As expected, crop biomass and yield diminished in residual P treatments of RPRE after the first cropping cycle, and this decrease, in general, was conversely proportional to the level of fertilization (as higher the P applications as lower the decrease in crop production). This sharp decrease was presumably due to a high soil P-absorption and/or P loses. From all annual applications of SFT in RPRE only 40A increased biomass and yield with time. In fact, in the 4th cycle, crop response from residual 160 kg P ha^{-1} was lower than the accumulative applications of 40 kg P ha^{-1} (x 4 years). This suggests that ≥ 40 kg P ha^{-1} $year^{-1}$ could gradually build-up soil available P in opposition to P fixation and P loses; and this practice is recommended against only one large amount of P application at the beginning of the cycle.

Maize yields for P80R and P160R were similar to those obtained with the high inputs of chicken manure (i.e. 12 t ha^{-1}), especially in the first cropping cycle. However, lower yields in RPRE in the following cycles confirmed that application rates were inadequate to get similar yields to those in CHME or there was some other limiting factor that was being corrected by chicken manure additions (e.g., improved soil moisture). From CHME we also could argue that despite relatively greater response of crop yields to 12 Mg chicken manure ha^{-1} (especially for beans), the current practice by farmers (3-6 Mg ha^{-1}) seemed to be a reasonable trade-off between satisfactory yields with low cost of inputs (i.e. manure) versus greater yields with greater input costs involved.

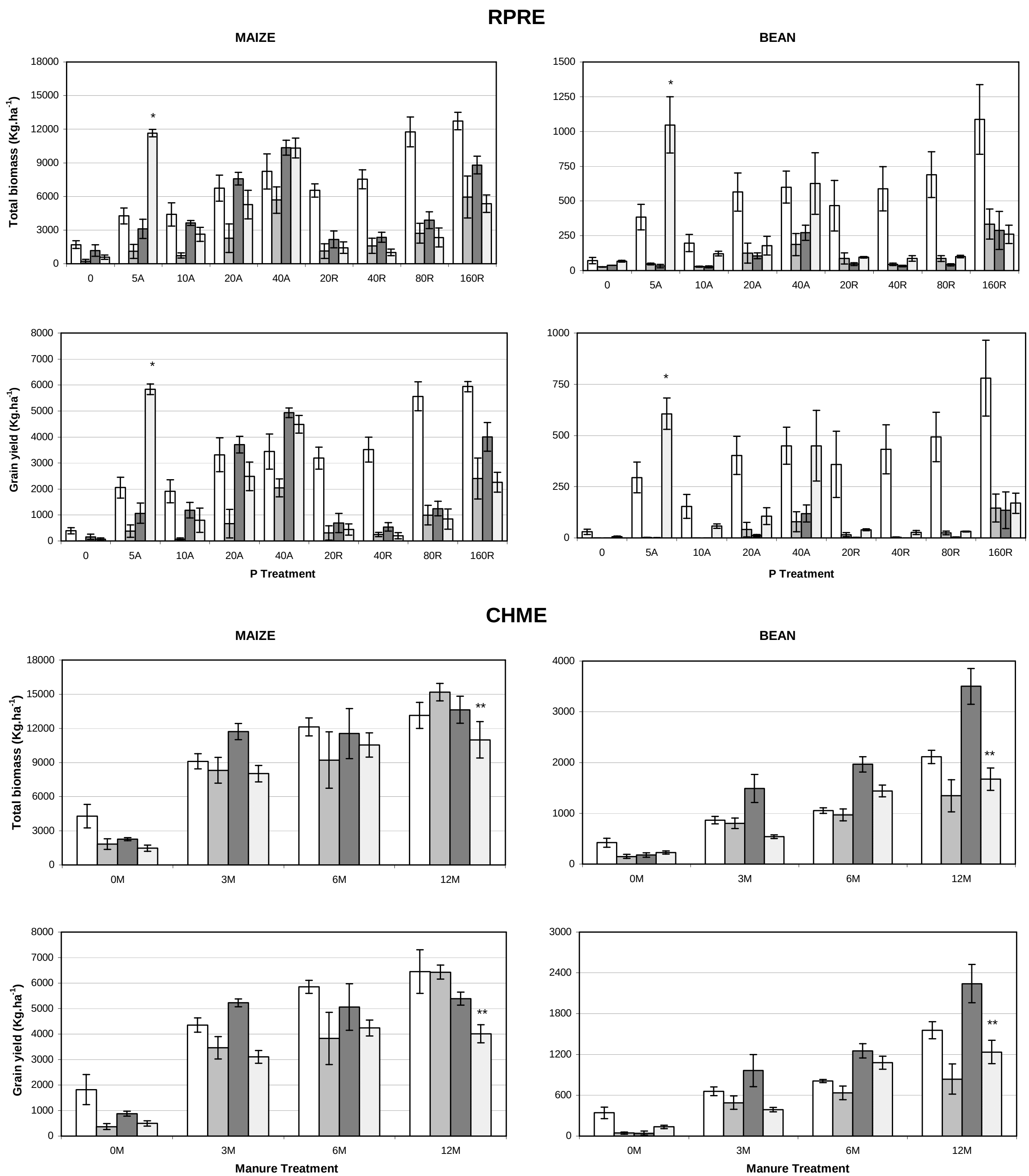

Figure 5. Total biomass and grain yield for maize and bean crops in RPRE and CHME during four years of experimentation. Vertical bars refer to standard errors of the mean (* application of 160 kg P ha^{-1}; ** chicken manure was not applied anymore).

Response of maize-bean rotation to different rates of P fertilizer and chicken manure on a Colombian ash soil: Modelling response using APSIM

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This paper reports progress in the development and testing of the APSIM modelling framework (Agricultural Production Systems Simulation Model; website www.apsim.info) towards functionality that can capture the release of N and P from various organic inputs, and for P from inorganic sources as well, and predict the growth of crops in situations where N and/or P is limiting. To this end the P routines in the Maize module have been incorporated in the APSIM Plant module so that the simulation of any crop that uses this module can, in principle, respond to P. In order to use this capability, the parameter set for any crop needs values for the critical P concentrations in the crop. These are used to estimate P demand by the crop to meet its daily growth requirements. Where the supply from soil is inadequate, the critical P concentrations determine the P stress being experienced, which is then used to reduce crop growth. The experiments involving P inputs as fertilizer or chicken manure to a maize-bean cropping system were carried out to provide a data set that would be suitable for further testing of the model and extending its application to a different crop (namely bean). The environment and soil (a very high P-fixing Andisol) at the Colombian location is in strong contrast to the soil in semi-arid Kenya on which the model was first developed.

The experimental plots were located at CIAT's 'San Isidro' experiment farm in Pescador, in the Andean hillsides of the Department of Cauca, Colombia (2º48' N, 76º33' W, 1500 m.a.s.l.). The area has a mean temperature of 19.3◦C and a mean annual rainfall of 1900 mm with bimodal distribution and two growing seasons. The soil is derived from volcanic ashes and is classified as an Oxic Dystropept (Inceptisol) in the USDA soil classification system and an Andic Dystric Cambisol in the FAO classification.

The simulations were done with APSIM v3.6. The model was specified to simulate the experimental treatments involving TSP, CM and urea assuming common starting conditions for all treatments, there was no resetting of any variables between crops. Measured data were used to specify the soil characteristics for the APSIM SoilWat and SoilN modules. A major objective of the study was to test the transferability of the model. Thus as few modifications as possible were made to the parameters for the crop, soil P and manure modules.

As the maize cultivar had not previously been modeled using APSIM and to improve fit of the maturity date simulated by the model with known harvest dates we decreased the tt_emerg_to_endjuv parameter from 230 to 220. No changes were made to the critical P concentrations that had been used for modeling maize crops in Kenya.

There has been no previous experience of modeling the common bean grown in Latin America using APSIM. We used the APSIM Plant module with the Navybean parameter set selecting the cultivar specific values for 'rb_short'. Changes were made to the parameters tt_emerg_to_endjuv (increased from 250 to 300 to make the simulated crop mature later) and to y_hi_max_pot (increased from 0.45 to 0.50 to increase the maximum harvest index potential of the simulated crops). Both changes were made to try to improve the fit with the observed data. In order to model a P response in bean it was necessary to create the parameters defining the critical P concentrations in the components of the bean crop. These were derived from analytical data for samples from the experiment (available at flowering, pod-filling and maturity in 2002, pod-filling in 2003 and 2004). The other parameter required was P_supply_factor for navybean in the Soil P module.

The chicken manure (CM) used each year in the experiment had been analysed for total C, N and P and also ammonium- and nitrate-N. These values were used to specify the inputs of manure in the model. In the APSIM Manure module, manure is characterized in terms of the three pools corresponding with the fresh organic matter (FOM) pools of the Soil N module. In other studies attempts have been made to link these pools to proximate analyses of organic sources. Here we have assumed that the C was distributed in the ratio 0:0.5:0.5 between the three pools. Further we assumed that all pools had uniform composition of C, N and P.

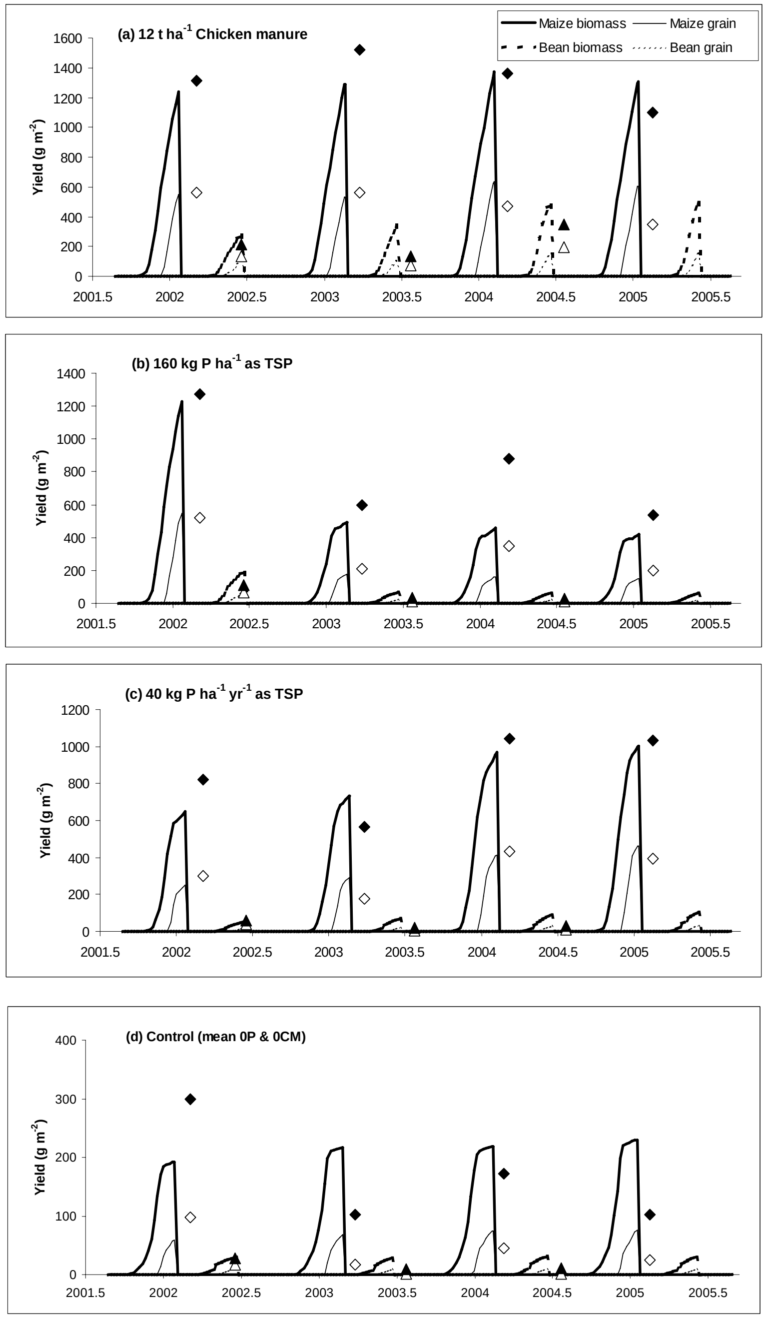

Figure 6. Comparison of observed (symbols) and predicted (lines) for total biomass and grain yield of maize and bean crops (2001-2005) for selected treatments. Note that the vertical scales differ for different treatments.

Soil P fractionation data were available only for the surface (0-10 cm) soil layer. We used the sum of resin P and bicarbonate Pi fractions as the estimate of labile P in soil. Based on published data on P sorption in soils similar to the experimental site, we estimated the P sorption for the surface layer to be 1000 mg kg^{-1} at the standard solution P concentration of 0.2 mg L^{-1}. No information was available for the subsoil layers. We have assumed that soil P decreases with depth and that P sorption increases in the subsoil. The values used are included in Table 1. Initial simulations used identical parameters in the Soil P module as were used to simulate a long-term experiment on an Alfisol in Kenya. However inspection of the output indicated that the rate of loss of availability of P applied as TSP was considerably faster on the Andisol than on the Alfisol. The parameter rate_loss_avail_P (fraction lost per year at 25°C) was increased from 0.5 to 0.8 to improve the fit of the model to the observed data.

Figure 6a shows a comparison of the observed and predicted crop yield through the eight seasons for selected treatments. For the 12CM treatment (Figure 1a) there is good agreement for the maize crops that produced some 1300 g m^{-2} total biomass and 600 g m^{-2} grain each year. The grain yield for bean was predicted well in 2002 and 2004 but not in 2003. Total biomass for bean was over-predicted (this is explored in more detail below). The 2003 bean crop was severely affected by diseases caused by *Rhizoctonia solani* and *Colletotricum lindemuthianum* which delayed maturity well beyond the normal 88 days and seemingly reduced yields. The simulation of the treatment without added P (Figure 6d) has much smaller yields of maize and bean. Comparing this treatment with 12CM shows that the model predicted a large response to input of P in this soil. The experimental data for the control treatments in the two experiments (0CM and 0P) showed considerable variation. In Figure 1d the observed data are the means of these two treatments. The other two treatments compare the effects of the one-time application of 160 kg P ha^{-1} as TSP (Figure 6b) with the annual input of 40 kg P ha^{-1} (Figure 6c). In both cases there is good agreement between the observed and predicted data. For the 160P treatment the yield of maize in the first crop is close that for 12CM, but the residual effect is not sufficient to maintain high yields in later seasons. These were the findings that led to the use of the higher rate of loss of available P in the model. With the parameterization used the model predicts the declining yields rather well. In contrast, the annual application of 40P was inadequate to yield as well as 12CM or 160P in the first season, but through time this treatment improves to yield better than 160P in the 2005 maize crop. Again the model captures this effect well.

Conclusion: The model simulated the observed data very well despite the very few and minor changes made, showing the robustness of the model. This is also the first experience of modelling beans with APSIM and will become the first published example of extending P routines to beans.

Developing high fertility trenches technology for high value crops in hillsides

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The hillsides agroecosystem in tropical America includes an area of 96 million hectares. Of this area around 25 million hectares are highly degraded and 53 million are under a rapid process of degradation. Colombian Andean region shows soil erosion problems from very light to severe. In Colombia the hillsides agroecosystem is characterized by the presence of coffee, plantains, pastures/grasses and annual crops (maize, beans, cassava, etc.). In this agroecosystem population pressure has lead to deforestation allowing new areas to enter into cultivation in steep slopes that are prone to erosion. It is anticipated that in 10 to 20 years time there will be water shortage in many towns of the Andean zone, therefore, it is necessary from now on, to take the measures to avoid it.

As part of an ongoing collaborative project between the CRC (Regional Corporation of Cauca) and TSBF-LAC, in several of the areas of influence of the project, farmers identified the need to intensify production systems in their farms through the use of high value crops (typically, vegetables and some short cycle fruits). One of the high priorities identified by farmers was the use of soil management methodologies to improve soil quality at farm level in strips where these vegetables could be grown with minimum edaphic limitations. Previous work conducted at San Isidro, Pescador, in the region, showed the feasibility of using high fertility trenches to maximize the effect of modest inputs (fertilizers, animal manures, green manures etc) that farmers could afford to increase yields. Many farmers in the region have taken the concept tested on station, and are now using the approach in their farms with their own adaptation and improvements, using the inputs to which they have more access in each location. The farmers involved in the project with CRC have requested this methodology to be included as part of the activities proposed to increase profitability of their production systems. CRC has requested to include and test the performance of high fertility trenches in several farms along the Cauca department. Preliminary data are being generated and will be reported next year.

Currently, small farmers are preparing the whole area of a piece of land for cultivation, leaving a bare soil subjected to active forces that cause erosion. Besides, farmers are practicing agriculture with limited economic resources. To establish economically viable and sustainable production systems, it is required an atmosphere of favorable policies and efficient use of resources. To face the problems of soil's fragility and to combat the problems of low productivity and degradation, strategies integrating genetic resources, technologies for soil and water conservation, use of fertilizers and biological control of insects and diseases, must be planned in a rational manner to improve livelihoods of farmers and to conserve natural resources. To restore degraded and abandoned soils, the development of high fertility contour trenches technology with the following objectives is proposed: a) regain use of abandoned lands, b) increase water infiltration and control soil erosion, c) improve soil fertility, and d) introduce high value crops. The main objective of the study is to increase productivity of Andean hillside soils through the management of systems that allow increasing their productive capacity and simultaneously are able to control soil losses, improve water supply to crops, and protect the environment while improving the quality of life of the farmers. The following are the specific objectives:

- Improve economical condition of farmers by conserving and improving soils and water resources avoiding degradation of productive soils and environment.
- Introduce the use of "high fertility trenches" as a way to avoid erosion and runoff production, to regain the use of abandoned lands and to improve soil productivity.
- To produce high value crops: vegetables, flowers, fruits, etc. for farmer's better economical conditions.
- To characterize and to evaluate plants (grasses, legumes, etc.) that can serve as soil cover crops and enhancers of soil quality.
- To transmit to technicians and farmers new methodologies to improve and conserve soils and water to produce high value crops.

The following methods were used:

- Choose in a farm (in agreement with the farmer) a degraded or low productivity area.
- Determine the degree of slope (for distances between trenches).
- With the help of a level, mark out a level curve in the middle of the plot and then parallels to countering the selected area.
- In each contour curve dig a trench of 30 cm wide and 25 to 30 cm depth through the length of the field.
- According to soil chemical analysis, add a mixture of lime, chicken manure and fertilizers to improve soil fertility.
- After a week, sow a high valuable crop (vegetables, flowers, fruits, etc.).
- If possible install a drip irrigation system.
- The land area between trenches will remain in its original state of vegetation to protect the soil against the impact of drops of rainfall.
- See Figure 7 for details on methodology.

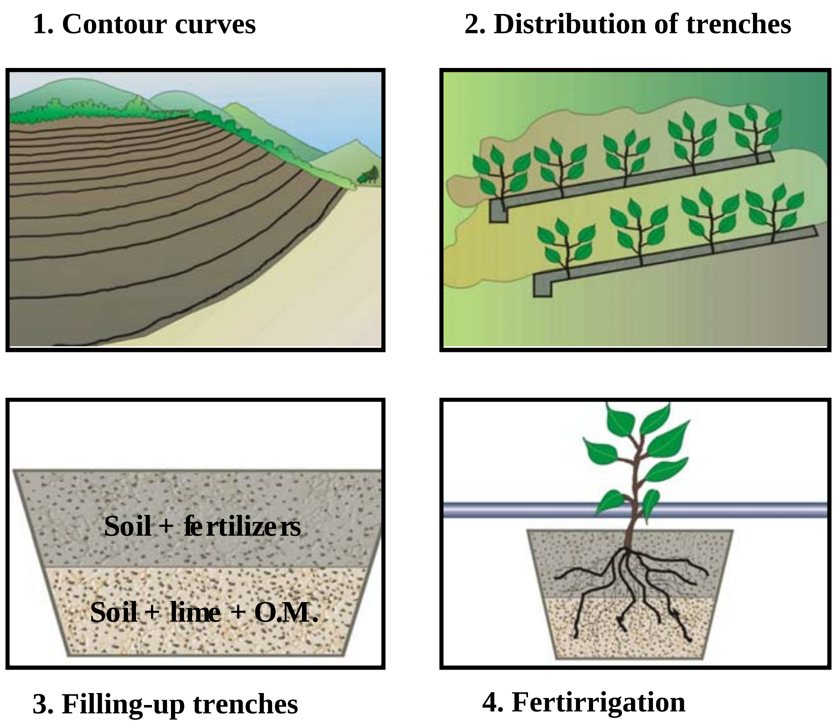

Figure 7. Trenches of high fertility used for cultivating commercial crops in degraded soils of Pescador – Cauca, Colombia.

Production cost and benefits of establishing one hectare of pepper in high fertility trenches: Table 4 presents the results obtained inone experiment located in hillsides of the Andes, San Isidro, Pescador, Department of Cauca (1500 masl, 1900 mm of precipitation and 19°C as average temperature) using pepper as testing crop. Data obtained in experimental plots are expressed in terms of one hectare.

Table 4. Production costs and economic benefits of pepper *(Capsicum anuum)* cultivation using high fertility trenches technology.

Description	Unit	Amount	Unit value US$	Total value US$
Activities				
Seedling	Wages	1.96	5.60	10.97
Ditches	Wages	12.32	5.60	68.99
Sowing	Wages	3.36	5.60	18.82
Weeding	Wages	7.84	5.60	43.90
Controls	Wages	3.64	5.60	20.38
Fertilizers	Wages	3.36	5.60	18.82
Irrigation	Wages	10	5.60	56.0
Harvesting	Wages	13.44	5.60	75.30
Subtotal				**313.18**

Materials				
Seed	kg	0.1	31.31	3.13
Insecticides	Liter	1.12	26.31	29.46
Fungicides	kg	1.96	17.54	34.38
Chicken manure	Mg	0.84	49.34	41.44
Calfos	50kg	4.48	5.26	23.56
15-15-15	50kg	1.4	37.72	52.80
MgO	50kg	0.28	20.61	5.77
Agrimins	50kg	0.28	24.56	6.87
Boxes	Box	267	0.57	152.20
Subtotal				**349.61**
Total expenses				**662.79**
Yields	Mg	4		
Price of sale	kg		0.35	
Profits				**737.21**

1 USD: $ 2280 Colombian pesos

Economical analysis shows that using this technology farmer could expect to have benefits of US$737 per hectare per cycle (4 months). However, small farmers can't afford to sow one hectare but small areas (50-1000 m^2). Therefore, the benefits are reduced. On the other hand they can also plant 2.0 to 2.65 crops per year. During the second and following years the income could be increased because they do not need to build the trenches.

Effect of disk harrowing intensity on soil sealing in a savanna oxisol of the Eastern plains of Colombia

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The main objective of this study is to evaluate the cumulative effect of disk harrowing intensity on the formation of surface sealing of an Oxisol (Typic Haplusdox isohyperthermic kaolinitic) of the eastern plains of Colombia, through physical characteristics such as structural stability, infiltration, sorptivity, run-off and soil losses. The main hypothesis is that the intensity of harrowing, represented by the cumulative number of disc passes, favors the formation of surface sealing in soils. Sealing and crusting is the natural reaction of the soil to the physical impact of the raindrops falling with high energy on the naked soil. Excessive farming exposes the soil to the impact of the raindrops which destroys the aggregates dispersing them into microaggregates and individual particles that later on are deposited on the surface of the soil, forming the seal that reduces water infiltration, soil aeration and increases run-off. Sealing diminishes considerably the entrance (acceptance) of water into the soil, and therefore the amount of available water to the crops. All this is associated with low structural stability, fine sands and low contents of soil organic matter.

The investigation was carried out in a farm located in Matazul, 40 km East of Puerto López (Meta), at 4° 5' N and 72° 58" W, 160 m.a.s.l, mean annual rainfall is 2,251 mm, average annual temperature 26°C, the soil is classified as an Oxisol (Typic Haplustox Isohyperthermic kaolinitic), extremely acid (pH 4.5-5.0), with low availability of total bases (0.3 $cmol_c\ kg^{-1}$), low content of P (2.6 $mg\ kg^{-1}$), high aluminum saturation, and low percentage of organic matter (3.5%) at 0-15 cm depth. Soil samples in 15 × 54 m plots were taken, at a depth of 1 cm, following a zigzag course in every treatment. The sampling was carried out 25 days after the harvest of corn; sampling points in every plot were geo-referenced, as well as the extreme points delimiting the plot, to facilitate its location in a map. By the time of sampling experimental plots had accumulated 16, 32 and 64 disk harrow passes in a maize crop; 2, 4 and 8 disk harrow passes under pastures with *Brachiaria dictyoneura;* to be compared with ecosystems of native savanna and gallery forest as controls.

Under field conditions, penetrability was measured using a penetrometer for crusts, soil strength was determined with a torquemeter special for crusts, which allows to measure soil strength up to 1 cm depth in kPa. Infiltration was determined using concentric rings. Results were adjusted to Kostiakov mathematical model to determine the basic infiltration and explain the dynamics of the cumulated water, as well as the infiltration rate and the sorptivity of the soil. Three measurements per trial plot were carried out. Infiltration readings were taken during two hours. Field moisture content, saturated hydraulic conductivity, moisture characteristics, bulk density, pore size distribution, air permeability, aggregate stability, soil texture and true density were evaluated in the laboratory.

For data analysis, the statistical package SAS, version 6.12, was used. A variance analysis (ANOVA) was carried out, to determine the effect of harrow passes on the formation of the seal and the effect on the physical and chemical properties of the soil, using the Duncan test of averages comparison to a level of $P<0.05$. A multivariate analysis of the data allowed establishing interrelations between the physical/chemical properties of the soil and the management systems.

The mean resistance values of penetrability and soil strength reported in Table 5 shows the effect of the use and management of the soil on its capacity to permit normal root development of crops. At the level of soil use, it is observed that the forest treatment reported lower mean values, while the highest values were in the treatments with grasses; the mean values were above the critical value (30 kgf cm-^{2}), which is considered restrictive for the development of roots. The effect of the number of disk harrow passes in grasses and maize presented a direct proportional relationship with soil strength.

Table 5. Values of penetrability and soil strength at 0-1 cm depth in treatments.

Treatment	**Penetrability (kgf/^{cm2})**	**Soil strength (kPa)**
Maize 2 passes	33.30	1.86 e
Maize 4 passes	10.58	7.09 e
Maize 8 passes	13.10	25.67 d
Pastures 2 passes	48.48	58.11 c
Pastures 4 passes	100.00	80.67 b
Pastures 8 passes	264.42	95.33 a
Native Savanna	13.85	67.67 c
Forest	0.25	0.61 e
LSD	-----	10.4
CV	-----	14.2
Pr >F	N.S	<0.0001

Means with the same letters in the same column don't present significant differences (P <0.05) for the Duncan Test.

Forest and maize 2-passes treatments showed the highest values in cumulated and rate of infiltration in 2 hours. Sorptivity presented a similar trend in forest and maize 2-passes with higher values of slope, in comparison with the other treatments. Table 6 shows the distribution of dry aggregates in two groups; (aggregates bigger and smaller than 2 mm). A prevalence of big aggregates in the grasses and native savanna treatments is observed, opposite to the maize treatments (with prevalence of small aggregates); the forest treatment presented a balanced distribution of aggregates. The effect of the quantity of harrow passes on the destruction of aggregates (bigger than 2mm) was more evident in the maize treatment; doubling the passes, approximately 50% of the big aggregates were destroyed; this action increases bulk density due to the repacking of the small.

The mean weight diameter (MWD) for dry aggregate size distribution presented highly significant differences between treatments. This demonstrated that the intensity of harrowing decreased significantly the MWD of the aggregates in maize and corroborated the role that pastures have as builders of big aggregates. The MWD shows that the quantity of disk harrowing passes influenced negatively the stability of the aggregates, contrary to the effect of the pasture roots that exerted a beneficial role in the structure and the stability of the soil, tying the aggregates and particles that form and maintain the structure.

Table 6. Mean weight diameter (mm) for aggregate distribution and stability in the different treatments.

Treatment	%percentage of aggregates		Mean Weight Diameter	
	> 2 mm	< 2 mm	Distribution	Stability
Maize 2 passes	56.01	43.99	3.23 c	1.13 c
Maize 4 passes	29.74	70.26	1.76 e	1.13 c
Maize 8 passes	19.87	80.13	1.23 f	1.00 c
Pastures 2 passes	84.72	15.28	5.10 a	5.56 a
Pastures 4 passes	82.80	17.20	5.03 a	5.93 a
Pastures 8 passes	79.80	20.20	4.86ba	5.73 a
Native savanna	79.33	20.67	4.76 b	4.60 b
Forest	44.16	55.84	2.50d	5.56 a
LSD	___	___	0.25	0.39
CV	___	___	4.06	5.85
Pr >F	NS	NS	<0.001	<0.001

Means with same letters in the same column don't present significant differences (P <0.05) for the Duncan Test.

Results in Table 7 shows the effect of a simulated rain (100 mm h^{-1}) on water infiltration, runoff and eroded sediments in each treatment. Maize treatments showed less cumulative infiltration values than pastures of forest. As the number of harrowing passes increased, more runoff and amount soil eroded was found. It is associated with soil sealing that impedes infiltration and increase run-off. Runoff under maize 8 passes was almost three times greater than that of maize 2 passes. Native savanna produced 11 mm of runoff indicating that under natural conditions the loss of water is high, almost 40% of the rainfall applied. It is important to note that these soils are dominated by fine to very fine sands and have low values of O.M. (>4.0%).

The results obtained indicate that the practices to be applied for improving soil physical conditions of these soils should be focused on increasing water infiltration and stabilizing soil structure, through a good combination of constructive tillage to promote root growth and to the use of mulch and soil covers to avoid the direct impact of rainfall on bare soil.

Table 7. Evaluation of the infiltration layer, run-off and eroded sediments using the mini-simulator of rains (100 mm/h intensity in 30 minutes).

Treatments	Accumulated applied layer (mm)	Accumulated infiltrated layer (mm)	Accumulated run-off layer (mm)	Accumulated eroded soil ($g\ m^{-2}$)
Maize 2 passes	55.90	49.10	6.80	8.54
Maize 4 passes	50.14	34.84	15.30	14.65
Maize 8 passes	48.06	22.46	25.60	19.23
Pastures 2 passes	54.42	53.32	1.10	1.22
Pastures 4 passes	51.19	50.39	0.80	0.31
Pastures 8 passes	50.33	49.73	0.60	0.00
Native savanna	45.58	34.18	11.40	8.13
Forest	52.30	52.30	0.00	0.00

Effects of tillage systems on soil physical properties, root distribution and maize yield on a Colombian acid-savanna Oxisol

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Acid-soil tropical savannas cover 243 million hectares (Mha) in South America. They are one of the most agriculturally rapidly expanding frontiers in the world. In Colombia, they cover an area of 17 Mha and are locally known as the "Llanos". In 1993, a long-term field experiment on sustainable crop rotation and ley farming systems was initiated on a Colombian acid-savanna soil to test the effects of grain legumes, green manures, intercrops and leys as possible components that could increase the stability of systems involving annual crops. The study has lasted for almost two rotational cycles, recognizing the fact that degrading or beneficial effects of various agricultural practices are always very small and only show up over long periods of time. Alternative systems, which reverse the deleterious effects of monocultures, are required and biophysical measures of sustainability need to be developed as predictors of system performance and health. Integration of crop/livestock systems (Agropastoralism) has been shown to be a highly successful strategy for intensifying agricultural production sustainably and reversing problems of degradation.

The challenge in sustainable crop rotation systems is to optimize short-term productivity while maintaining long-term soil fertility. The situation becomes even more complex when more than two crops are involved in the rotation. Appropriate tillage practices and incorporation of leguminous crops into the rotation can sustain productivity. Legume roots have been found to be efficient in acquiring P and Ca in low fertility acid savanna soils. Here we report the results from the sixth (6^{th}) year of the experiment and one year after implementation of the no-till and minimum tillage systems, during the second 5-year phase, focusing on maize-based systems. The major objective of this study was to determine the effects of no tillage and minimum tillage on (i) soil physical properties, (ii) root distribution, and (iii) maize grain yield on an acid-savanna soil under different agropastoral treatments.

Studies were carried out at the CIAT-CORPOICA experimental station, Carimagua (4°37'N, 71°19'W and 175 m altitude) on the eastern plains of Colombia (Llanos orientales). Measurements were made in selected treatments of the long-term field experiment established in 1993 to investigate sustainable crop rotation and ley farming systems for the acid-soil savannas (CULTICORE experiment). The experimental design was a split-plot with four randomized blocks (replications), with main plots assigned to upland rice-based (fertilizer lime) systems or maize-based (remedial lime) systems. Only results from maize-based systems for the cropping year 2000 are reported in this study. This was the sixth year of rotational cropping after establishment of the experiment, but one year after implementation of the no-till (NT) and minimum tillage (MT) systems. The maize-based systems include the following treatments: maize monoculture (MMO), maize-soybean rotation (MSR), maize-soybean green manure rotation (MGM), native savanna (control) (NSC) and maize-agropastoral rotation (*Panicum maximum* with forage legumes) (MAP). Tillage system NT in this study means that the plots were subjected to conventional tillage (CT) during the first 5-year period and were then sown with a direct-drilling sowing machine, herein referred to as direct seeding i.e. there was no intervention in the soil before planting. Soil physical parameters measured in this experiment included bulk density, total porosity, field moisture content and volumetric moisture content at 0, 7.5, 100 and 1500 kPa suction levels. Root samples were collected at 72 months (6 years) after establishment of the long-term experiment. This was done using the root coring method. Grain yields of maize were recorded after harvest. The grain yields were obtained by manual harvesting from each plot, in 5 rows of maize of 10 m long (4m x 10m (40 m^2)). Grain weights were adjusted to 19% of moisture content.

Because of differences in the amount of residue and the intensity of tillage, different tillage systems affect the physical properties of soil such as water content, bulk density, penetration resistance and soil porosity. Changes in soil physical properties might develop slowly after initiation of conservation tillage. Few significant results between NT and MT systems were obtained for bulk density under MSR (at the 0-5 cm soil layer); MMO, NSC and MAP (at the 5-10 cm soil layer); and MAP (at the 10-20 cm soil layer). Direct seeding (NT) generally had lower bulk density and higher total porosity for all agropastoral treatments and soil layers as compared to the MT system. On average, within each soil layer and across all agropastoral treatments, field moisture content and volumetric moisture content at all suction levels were similar for both tillage systems. In both tillage systems and under all agropastoral treatments, there was a decrease in volumetric moisture content with increasing water suction ($P < 0.05$)

The influence of NT and MT on distribution of maize roots under different agropastoral treatments is summarized in Table 8. The MT system seemed to improve root length. The average root length for NT agropastoral treatments was 0.70, 0.47, 0.37 and 0.33 km m^{-2} for the 0-5, 5-10, 10-20 and 20-40 cm soil layers, respectively. For the MT agropastoral treatments, it was 0.84, 0.55, 0.58 and 0.49 km m^{-2}. On the other hand, within the MT system, higher root length results were obtained under MSR agropastoral treatment at the 5-10 cm soil layer and also under MGM at the 20-40 cm soil layer. There was a decrease in maize root length with increasing soil depth for all tillage systems and agropastoral treatments ($P < 0.05$). Enhanced biological activity and increased nutrient availability has been reported to influence root distribution in the topsoil.

The MT system also appeared to improve root biomass of maize in the 0-5 and 20-40 cm soil layers. The average values were 467 and 43 kg ha^{-1} for the 0-5 and 20-40 cm soil layers, respectively, for NT and 595 and 56 kg ha^{-1} for the same soil layers for MT (Table 8). There was a decrease in maize root biomass with increasing soil depth within both NT and MT systems ($P < 0.0001$). Higher root biomass adds organic matter and improves soil fertility through rapid turn over and addition of nutrients. This could contribute to improved crop yields. On average, specific root length was higher under MT as compared to NT system. These results highlight the fact that tropical forage pastures in association with forage legumes (under treatment MAP) had developed a finer root system and therefore are most likely to positively influence productivity under this treatment.

Between the two tillage systems, higher maize grain yields ($P < 0.1$) were obtained under NT system treatments MMO, MSR and MGM as compared to the same treatments under MT system (Table 9).

Native savanna (control) (treatment NSC) consistently produced the lowest maize grain yields. Within the NT system, treatments MMO, MSR, MGM and MAP showed higher maize grain yields as compared to NSC, with MGM giving the highest yield. The trend was MGM > MAP > MSR > MMO > NSC (Table 5). The values for maize grain yield ranged from 1280 kg ha^{-1} (under NSC) to 4705 kg ha^{-1} (under MGM). These results indicate that the MGM treatment with NT soil conditions were adequate for implementing the no-till system. The average maize grain yield under all the NT system agropastoral treatments was 3566 kg ha^{-1}. Within the MT system, treatment MAP showed higher maize grain yield as compared to the other agropastoral treatments. The trend was MAP > MSR > MGM > MMO >NSC. The values for maize grain yield ranged from 1150 kg ha^{-1} (under treatment NSC) to 4117 kg ha^{-1} (under treatment MAP). The average maize grain yield under all the MT system agropastoral treatments was 2473 kg ha^{-1}.

Table 8. Effects of no-till (NT) and minimum tillage (MT) on root distribution of maize under different agropastoral treatments[#]

Soil depth (cm)	Agropastoral Treatment	Root length km m^{-2}		Root biomass km ha^{-1}		Specific root length m g^{-1}	
		NT	MT	NT	MT	NT	MT
0 – 5	MMO	0.75 a	0.87 a	494 a	660 a	15 a	13 a
0 – 5	MSR	0.49 a	0.69 a	468 a	508 a	11 a	14 a
0 – 5	MGM	0.43 a	0.58 a	456 a	658 a	9 a	9 a
0 – 5	NSC	0.95 a	0.84 a	513 a	401 a	19 a	21 a
0 – 5	MAP	0.86 a	1.23 a	403 a	747 a	21 a	17 a
5 – 10	MMO	0.45 a	0.50ab	57 ab (b)	84 a	79 a	60 a
5 – 10	MSR	0.51 a	0.84 a	57 ab (b)	83 a	90 a	101 a
5 – 10	MGM	0.26 a	0.31 b	46 b (b)	52 a	57 a	60 a
5 – 10	NSC	0.16 a	0.47 ab	§188 ab(ab)	99 a	32 a	48 a
5 – 10	MAP	0.96 a	0.61 ab	*§275 a (a)	75 a	§35 a	81 a
10 – 20	MMO	0.41 a	1.03 a	§53 a	102 a (a)	77 a	101 a
10 – 20	MSR	0.54 a	0.62 a	92 a	61 ab (ab)	59 a	102 a
10 – 20	MGM	0.26 a	0.27 a	*§242 a	52 b (b)	*§11 b	52 a
10 – 20	NSC	0.16 a	0.35 a	§142 a	49 b (b)	*§11 b	71 a
10 – 20	MAP	0.46 a	0.61 a	53 a	56 ab (b)	87 a	109 a
20 – 40	MMO	0.39 a	0.35 b	70 a	48 a	56 a	73 a
20 – 40	MSR	0.17 a	0.39 b	31 a	43 a	55 a	91 a
20 – 40	MGM	*§0.20 a	0.96 a	25 a	72 a	80 a	133 a
20 – 40	NSC	*§0.54 a	0.15 b	62 a	54 a	87 a	28 b
20 – 40	MAP	0.33 a	0.61 ab	27 a	65 a	122 a	94 a

[#]For a given root parameter and depth as well as tillage system, means within a column followed by the same letter (s) are not statistically significantly different, using the LSD test at $\alpha = 0.05$ and $\alpha = 0.1$; the letter(s) in parentheses show significant statistical results at $\alpha = 0.1$ at the given soil depth and tillage system; the asterisk (*) and paragraph (§) indicate a significant statistical difference in the concerned parameter between the corresponding two tillage systems (i. e. NT and MT) for a given agropastoral treatment at $\alpha = 0.05$ and $\alpha = 0.1$, respectively.

It is clear from the above results that the NT system, on average, produced higher maize grain yields as compared to the MT system and that treatment NSC produced the lowest yield among all the agropastoral treatments. Crop production on tropical and subtropical acid soils is normally limited by aluminum toxicity. This could have been the possible cause of the very low maize grain yields under treatment NSC, since the soils had very high aluminum (90%) saturation.

Maize grain yield results from this investigation indicate that the agropastoral treatments under NT, as compared to the same treatments under MT system, had created soil conditions adequate for implementation of the no-till system on the Colombian savanna Oxisols. The positive influence of legumes in the rotations was thus realized in this study. This would be good news for the resource-poor farmers in this region, as they would easily adopt this relatively cheaper technology for increased soil productivity and environmental conservation. Maize yields on native savanna soils were markedly lower than the rest of the agropastoral treatments, indicating the need for improved soil conditions in subsoil layers for root growth of maize.

Table 9. Effects of no-till (NT) and minimum tillage (MT) on maize grain yield under different agropastoral treatments#

Agropastoral treatment	**Grain Yield** -------------------kg ha^{-1}-----------------------	
	NT	**MT**
MMO	*§3802 a	2035 bc (c)
MSR	§3804 a	2691 b (b)
MGM	*§4705 a	2370 b (bc)
NSC	1280 b	1150 c (d)
MAP	4239 a	4117 a (a)

#For each tillage system, means within a column followed by the same letter (s) are not statistically significantly different, using the LSD test at α = 0.05 and α = 0.1; the letter (s) in parentheses show significant statistical results at α = 0.1 within the given tillage system; the asterisk (*) and paragraph (§) indicate a significant statistical difference in yield between the corresponding two tillage systems (i. e. NT and MT) for a given agropastoral treatment at α = 0.05 and α = 0.1, respectively.

Inorganic and organic phosphorus pools in earthworm casts (Glossoscolecidae) on a Brazilian rainforest Oxisol

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We compared differences in soil phosphorus fractions between large earthworm casts (Family Glossoscolecidae) and surrounding soils, i.e., Oxisols in 10 year-old upland agroforestry system (AGR), pasture (PAS), and secondary forest (SEC) in the Central Brazilian Amazon. AGR and PAS both received low-input fertilization and SEC received no fertilization. We found that earthworm casts had higher levels of organic hydroxide P than surrounding soils, whereas fertilization increased inorganic hydroxide P. Inorganic P was increased by fertilization, and organic P was increased by earthworm gut passage and/or selection of ingested materials, which increased available P (sum of resin and bicarbonate fractions) and moderately available P (sum of hydroxide and dilute acid fractions), and P fertilizer application and land-use increased available P. The use of a modified sequential P fractionation produced fewer differences between earthworm casts and soils than were expected. We suggest the use of a condensed extraction procedure with three fractions (Available P, Moderately Available P, and Resistant P) that provide an ecologically based understanding of the P availability in soil. Earthworm casts were estimated to constitute 41.0, 38.2, and 26.0 kg ha^{-1} of total available P stocks (sum of resin and bicarbonate fractions) in the agroforestry system, pasture, and secondary forest, respectively.

Evaluation of *Brachiaria humidicola* accessions for nitrification inhibition ability

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We have reported earlier that *B. humidicola* CIAT 679 has the ability to inhibit nitrification by releasing inhibitory activity from roots (NI activity). This is based on evaluation of germplasm accessions that have apomictic mode of reproduction. This makes it extremely difficult to use this ability in a breeding program to transfer the ability to inhibit nitrification to other *Brachiaria* grasses that lack such ability unless we find genetic variability for this trait among sexual accessions of *B. humidicola*.

During this year, we evaluated 11 accessions of *B. humidicola*, that are believed to have the sexual mode of reproduction, along with the standard cultivar of CIAT 679 and *Panicum maximum*. Sexuals of *B. humidicola* can be used in a *Brachiaria* breeding program as they can be hybridized with other *Brachiaria* species. Plants were grown in a sandy loam Oxisol from the Llanos (Matazul) of Colombia (1 kg of soil/pot) under greenhouse conditions. The details of growing conditions and culture details were similar to that reported in the Tropical Grasses and Legumes annual report of 2004. After 120 d of growth, plants were removed from soil, and root exudates were collected and NI activity was extracted as described earlier (see annual report of 2004) and quantified using the modified bioassay that was developed at JIRCAS (see annual report of 2004 for details on the bioassay methodology).

Total NI activity released from roots of four plants during a 24 h varied from 62.4 to 207.2 AT NI among the sexual accessions of *B. humidicola*. The standard cultivar of CIAT 679 released about 66.4 AT NI. The NI activity released from *P. maximum* is only about 0.55 AT NI during 24 h period, thus confirming our earlier observations that this tropical grass lacked such NI ability.

Our results indicated that most of the sexual accessions of *B. humidicola* have similar NI ability to that of standard cultivar CIAT 679, and that only one sexual accession has nearly three times NI activity released compared to that of the standard cultivar. Thus, the NI ability of *B. humidicola* CIAT 679 is not confined to the accessions that have apomictic mode of reproductive behavior, but exists also in the accessions that have sexual mode of reproductive behavior. Our results indicate that some of these sexual accessions can be used as a source of NI trait for the *Brachiaria* breeding program to regulate NI activity to improve N use efficiency in pasture systems.

Field validation of the phenomenon of nitrification inhibition from *Brachiaria humidicola*

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A range of Nitrification Inhibition (NI) activity has been measured for diverse accessions of *B. humidicola* and other tropical grasses under glasshouse conditions, as part of collaborative research between JIRCAS and CIAT. As a continuation of these research efforts, a long term field experiment was planned to validate the phenomenon of NI under field conditions and to test the hypothesis that the NI activity is a cumulative factor in soils under species that release the NI activity from root exudates. Given the vast areas currently grown in the tropics on tropical grasses, an understanding of the NI process and the possibility of managing it to improve N use efficiency, reduce nitrate pollution of surface and groundwaters as well as reduce net impact on global warming through reduced emissions of nitrous oxide, could have potentially global implications. Various tropical grasses showing a varying degree of NI activity were selected for the experiment and a soybean crop and a grass (*P. maximum*) that lacks the NI activity were selected as controls.

The experiment was initiated in September 2004 at CIAT-HQ at Palmira, Colombia on a fertile clayey Vertisol (pH 6.9), and with an annual rainfall of 1000 mm and mean temperature of 25 C. Two accessions of *B. humidicola* were used: the commercial reference material CIAT 679, which has been used for most of our previous studies, and the high NI activity *B. humidicola* accession CIAT 16888. The *Brachiaria* Hybrid cv. Mulato was included for having moderate NI activity and *Panicum maximum* var. common was used as a negative non-inhibiting control. Soybean (var. ICAP34) is also used as a negative control due to its known effect on promoting nitrification. A plot without plants is used as an absolute control.

Treatments were placed in plots of 10 m x 10 m with three replications and distributed in a completely randomized block design. Soybean was planted from seeds and the grasses were propagated from cuttings. Soybean was inoculated with the Rizhobium strain CIAT 13232 to favor biological nitrogen fixation. Irrigation was provided to the field as required and two applications of broadcast fertilization were made at 30 and 60 days after planting on each plot, except within two 1 m^2 subplots demarcated in each plot, where the same levels of fertilizer were applied in solution to favor a more homogeneous distribution of the applied nutrients within the soil. Each application consisted of an equivalent dose of (kg ha^{-1}): 48N, 24K, 8P, 0.2 Zn, 0.2 B. The nitrogen source was ammonium sulfate. Weed control was done using Glyphosate in the bare soil plots and in the soybean plots before planting. During the soybean growing cycle manual weeding was done in such plots.

At harvest, soybean plants including roots were removed from the field when they had reached full maturity and the grain was already dry. The plants were separated into roots, shoots and grain, and a representative subsample taken for measuring dry matter content and N analysis. Plants of *P. maximum* were cut at approximately 20 cm height twice during the crop cycle. From each cut a representative subsample collected for dry weight and N analysis. The Brachiaria Hybrid cv. Mulato was cut at 20 cm height while the *B. humidicola* accessions were cut at 10 cm height. Similar procedure used for cv. Mulato was used for *P. maximum*. At harvest time, soil was carefully collected in the rizhopane of all species with an auger from the top 10 cm of the soil within each subplot. Four samples were collected in each sub plot and pooled to obtain a composite sample. Samples were carefully managed and only the soil adhered to the roots was removed and used for soil analysis. Once the rhizosphere soil was collected, it was allowed to air dry and then was finely ground to <0-1 mm mesh. Soil was analyzed for nitrate and ammonium content using KCl extracts and colorimetric determination. Fresh rhizoplane soil was used for microbial counting of nitrifier organisms. Gas samples for measuring N_2O fluxes were collected monthly. Once a year, soil incubation studies were conducted using rhizosphere soil, to monitor nitrogen dynamics and fluxes of N_2O.

So far two soybean crops have been harvested (February and August, 2005). In this report we present the data collected during the second cropping season and the accumulated fluxes of N_2O over one year. In Figure 8 we present the biomass harvested during the second crop cycle (April- August, 2005). Total yield of *P. maximum* and the *Brachiaria* hybrid Mulato were similar and clearly higher than the biomass from other species. Soybean had a total biomass slightly lower that the *B. humidicola.* Due to better plant coverage, biomass production of all the grasses but more particularly of the *B. humidicola* accessions was higher than during the initial cropping season.

Total N uptake by plants (in the harvested components) followed a similar trend of biomass accumulation. It is evident that both *P. maximum* and the Hybrid Mulato are extracting more N than what is being added as fertilizer, and consequently a net N mixing from the soils is occurring. Soybean is balanced regarding N application/uptake while the *B. humidicola* plots are removing less N than what is being added as fertilizer. The grain yield of soybean was similar in the two cropping seasons (1.6 Mg ha^{-1}) which is slightly lower that the commercial average in the region.

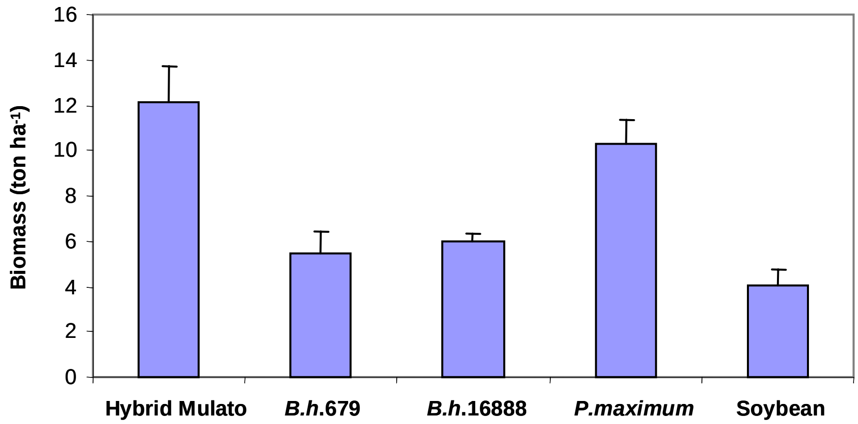

Figure 8. Total biomass harvested during the second cropping cycle (April- August 2005).

Soil Nitrate. In Figure 9 we show the nitrate levels in the top soil at harvest time. As expected the bare soil plots showed higher levels of nitrate more likely as a result of lack of plant N uptake. The soybean plots as well as the plots under the Brachiaria hybrid Mulato and *P. maximum* also had high levels of soil nitrate, while the *B humidicola* accessions clearly showed lower nitrate concentrations. The lower N uptake by 2 accessions of *B. humidicola* suggest a lower rate of nitrification with these two grasses or alternatively higher nitrogen losses.

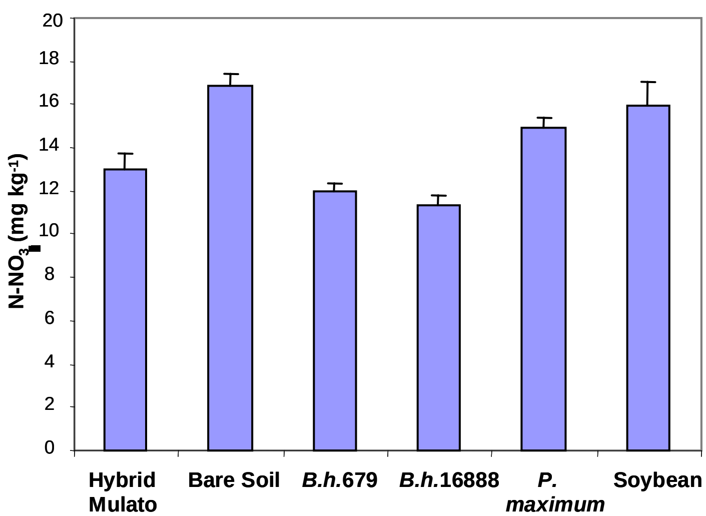

Figure 9. Nitrate levels in the top soil (0-10 cm) at harvest time.

Nitrous oxide emissions. In Figure 10, we show the accumulated fluxes of Nitrous Oxide (N_2O) over the period of September 2004 – August 2005. Annual emissions of N_2O were significantly lower in plots with *B. humidicola* and *P. maximum* than in the other plots. Fluxes were highest in the bare soil plots. These results support the view that *B. humidicola* is effectively inhibiting the nitrification process. However, *P. maximum* is also resulting in lower net emissions of N_2O but this may be attributable to the much higher nitrogen uptake by the plants which may limit the total amounts of N available for nitrification, assuming that the grass is able to take up N from the soil in ammonium form.

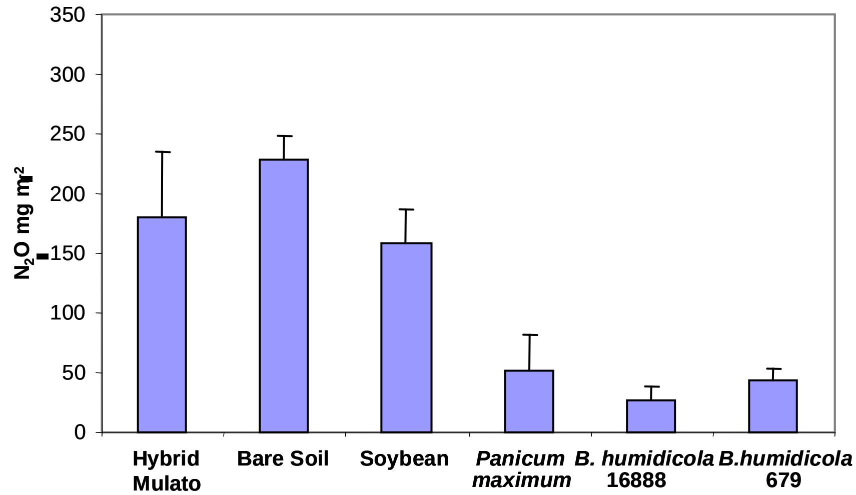

Figure 10. Accumulated fluxes of N_2O over one year period (September 2004 – August 2005). Two cropping cycles were included.

Soil Nitrification rates. Fresh rhizosphere soil was incubated to assess their mineralization rates in which soil samples are incubated with appropriate levels of ammonium and phosphate to favor nitrification. Chlorate is added to block the conversion of nitrite to nitrate and rates of nitrite accumulation (which are easier to measure than nitrate accumulation) are registered over time. In Figure 11 we show the results from the incubation test. The trend was similar than that with the N_2O fluxes. Both *B. humidicola* and *P. maximum* showed significantly lower nitrification rates than bare soil and soybean.

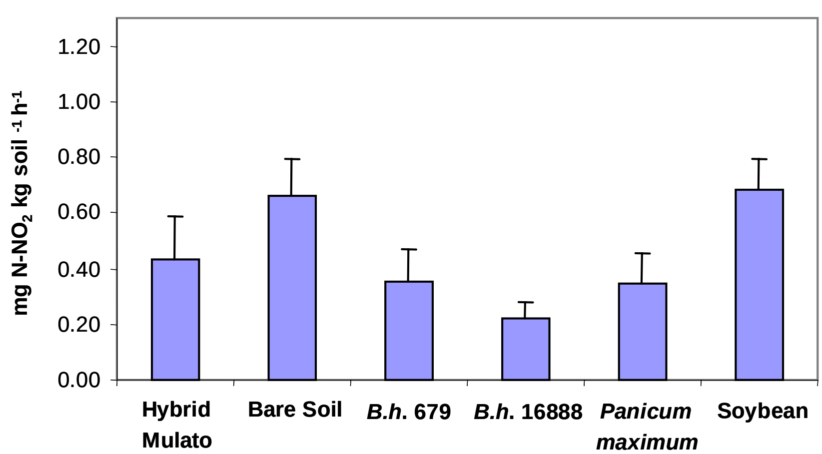

Figure 11. Nitrification rates from incubated soils.

No clear trend was observed for nitrate and ammonium levels in soil extracts. However, the significantly lower levels of inorganic soil under *B humidicola* suggest however that this species is likely favoring the flow of applied N into organic pools in the soil (Microbial N and Soil organic matter-N). Another indirect indication of this comes from the relatively low levels of nitrate estimated to be leached. This may need to be investigated in more detail in subsequent crop cycles. The incubation method to estimate nitrification rates used for this study is highly sensitive to detect even small differences in nitrification rates. In the next crop cycle, attempts will be made to monitor more frequently the nitrification rate of the plots during the crop season.

The total amount of N lost to the atmosphere as N_2O in the bare soil plots corresponds to approximately 1.6% of the applied fertilizer-N. This figure falls within the range reported in the literature for tropical soils. With *B. humidicola* net N_2O emissions were 12-20% less than the bare soil plots. This highlights the potential of these grasses in contributing to mitigation of climate change due to greenhouse effects.

Enhancing the productivity of crops and grasses while reducing greenhouse gas emissions through bio-char amendments to unfertile tropical soils

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Tropical savannas of Africa and Latin America represent the last frontier where agriculture can expand in the near future. The land is however dominated by very acid and infertile soils, which limit the adaptation and productivity of most crops and forages. Despite that liming and fertilizers could overcome these constraints, frequently they are not available or are too expensive and have had only limited use. In the Amazon rainforest, under similar soil conditions, indigenous knowledge generated millennia ago, lead to the creation of the so called Amazonian Dark Earths: highly productive and sustainable soils built through mixing infertile native soils with charcoal (bio-char), fish bones, nut shells etc. There is a growing interest to replicate these Dark Earths in other tropical environments where low fertility soils are predominant. There is a growing number of reports showing that in several soil types and climatic conditions, the use of bio-char in soils result in a significant increase in the productivity of a wide range of crops. Preliminary glasshouse experiments showed that the use of bio-char as amendment in soils from acid savannas resulted in large increases in biomass and yield of soybean and grasses growing in pots. In order to assess the effect on crop productivity under field conditions of amendments of soils with bio-char in the acid savannas of Colombia, a long-term field experiment was established in 2002. Here we present some of the results from that experiment.

The experiment was located on an clay-loam oxisol (Typic Haplustox) at the Matazul private farm in the Eastern Colombian Plains (4°19'N, 72°39'W). Annual rainfall is 2200mm and average annual temperature is 26°C. Plots were established after burning native vegetation, following farmer practices in the region. Lime was applied (2000 and 500 kg ha^{-1} for the crop and pasture plots respectively, the native savanna plots did not receive any lime or fertilizer application). One month after lime application, three levels of bio-char were applied to the plots: Control (0), 8 Mg bio-char ha^{-1} and 20 Mg bio-char ha^{-1}. The bio-char was produced locally from wood of mango trees using traditional methods. The bio-char was ground to <2mm, broadcasted on the soil surface and then incorporated by disking to 5 cm depth. Four months later, at the beginning of the rainy season, maize (Cultivar H-108) was sown as well as *Brachiaria dictyoneura* (var Llanero). Native savanna was allowed to re-grow on some of the plots. Experimental plots are $20m^2$ (4 x 5m) each and each treatment has 3 replications within a randomized complete block design. The maize plots received annual fertilizer applications equivalent to (per hectare basis) 160 kg N, 40 kg P, 60 kg K, 15 kg Mg and also micronutrients. The grass plots received annual doses equivalent to 30 kg N, 10 kg P and 15 kg K ha^{-1}. Periodically, the grass and the native vegetation (mostly native grasses) were cut to a height of 10 cm simulating grazing and the biomass produced in each interval was registered. Maize was harvested at full grain maturity. Annually soil samples are collected at various soil depths to assess several physicochemical parameters Gas exchange between the soil and the atmosphere was monitored monthly over a three-year period using the closed chamber method. Gas samples were analyzed for CO_2, CH_4 and N_2O using a gas chromatograph with ECD and FID detectors.

Table 10 shows values of selected soil parameters two years after the addition of bio-char. pH increased though not significantly in all plots receiving bio-char as compared with the control. Not significant differences were observed in the Redox potential of the soils, but clear increases in the availability of P and K were found in response to bio-char additions. No net change in total N in the soils was registered, though reduced nitrogen availability to plants may be anticipated as bio-char can adsorb inorganic N. The carbon content in the soils that received bio-char increased significantly and stays approximately constant over time (inter-annual data not showed). This suggests a very low turnover rate of the applied C in the soil despite very high temperatures and annual rainfall that would be expected to accelerate the breakdown of the applied bio-char. This amendment seems therefore to have very large residence times in the soils confirming its potential as a toll for long term C sequestration in soils. Despite that the bio-char was incorporated in the top 5 cm of the soil a significant migration to lower soil layer is evident from the ^{13}C data. ^{13}C of the applied bio-char has an isotopic ^{13}C label of approximately –26%o, while the ^{13}C label of the soil organic carbon is very homogeneous at approximately –12.5%o. We used ^{13}C signatures of the soil to track movement of bio-char in the soil profile. The bio-char migration has proceeded faster in the savanna plots followed by the pasture plots, while in the crop sites very little migration has occurred. Reasons for this are currently being investigated as well as the influence of bio-char on soil hydraulic functions and nutrient leaching.

Table 10. Changes in selected soil parameters after 2 years of Bio-char additions to soils.

Plant type	**Depth** (cm)	**Bio-char dose** (mg ha^{-1})	**pH**	**N-Total** (mg kg^{-1})	**P-Brayll** (mg kg^{-1})	**K** (cmol kg^{-1})	**% C**	**$\delta^{13}C$**
Savanna	0 – 5	0	4.29a	1306.22b	3.00b	0.06b	1.89b	-12.83b
Savanna	0 – 5	20	4.38a	1490.32a	3.14a	0.09a	2.63a	-14.02a
			ns	**	***	***	***	**
Savanna	5-10	0	4.3a	1403.5a	2.76b	0.04525b	1.58b	-12.5b
Savanna	5-10	20	4.3a	1320.86a	3.63a	0.0648a	2.76a	-18.03a
			ns	Ns	**	***	**	***
Pasture	0 – 5	0	4.41a	1421.44a	3.12a	0.07b	2.01b	- 12.97 b
Pasture	0 – 5	20	4.45a	1505.75a	3.46a	0.10a	2.65a	-15.86a
			ns	Ns	*	***	***	***
Pasture	5-10	0	4.37a	1358.81a	2.49b	0.03b	1.74b	-12.3b
Pasture	5-10	20	4.42a	1338.99a	3.05a	0.07a	2.19a	-13.27a
			ns	Ns	***	***	***	***
Crop Rotation	0 – 5	0	4.1a	1625.89a	7.48a	0.12a	2.29a	-12.42a
Crop Rotation	0 – 5	20	4.34a	1321.02b	7.37b	0.18a	2.36a	-13.01a
			ns	***	***	ns	ns	ns
Crop Rotation	5-10	0	4.28b	1397.49a	3.83a	0.12a	2.5a	-13.15a
Crop Rotation	5-10	20	4.92a	1207.66b	3.42a	0.09b	2.21b	-12.78a
			**	**	ns	**	**	ns

For a given soil depth and plant type, values followed by the same letter indicate non significant differences (P<0.05)

As indicated in Figure 12 and Table 11, additions of even low doses of bio-char to soils results in a net cumulative increase in total biomass of maize, improved pasture and native savanna vegetation. Yields of maize were similar in all treatments during the initial year but significantly increased due to bio-char use in the two subsequent years. In the third year, yields increased from 5.7 Mg ha^{-1} (control) to 6.6 and 7.3 Mg ha^{-1} for the low and high dose of bio-char respectively. Forage production from *B. dictyoneura* increased by 26% and 55% in the second year relative to the control in the low and high bio-char plots respectively. Total biomass production on the native vegetation trials was slightly increased from 2.9 Mg ha^{-1} (control) to 3.8 Mg ha^{-1} in the high bio-char dose, but was similar to the control at the low dose. The reason for the increase in plant total biomass and productivity can be attributed to increases in the availability of soil nutrients (P, K and probably some micronutrients) as well as changes in the cation exchange capacity of the soils which are being investigated. Higher soil moisture retention in the soil is another feasible explanation that will be confirmed by ongoing research. The effects of bio-char addition remain after three years and show that the positive impact may last even longer, pointing to a sustainable increase in soil quality.

Table 11. Effect of Bio-char additions on aerial biomass (Mg ha^{-1}) of pastures and Native Savanna vegetation

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Bio-char dose (Mg ha^{-1})	***B.dictyoneura***			**Native Savanna**		
	2003	**2004**	**2005**	**2003**	**2004**	**2005**
0	0.72	1.41	4.73	0.95	1.84	2.91
8	1.35	1.75	5.66	1.72	2.16	3.84
20	1.10	2.60	5.97	1.94	2.22	3.84

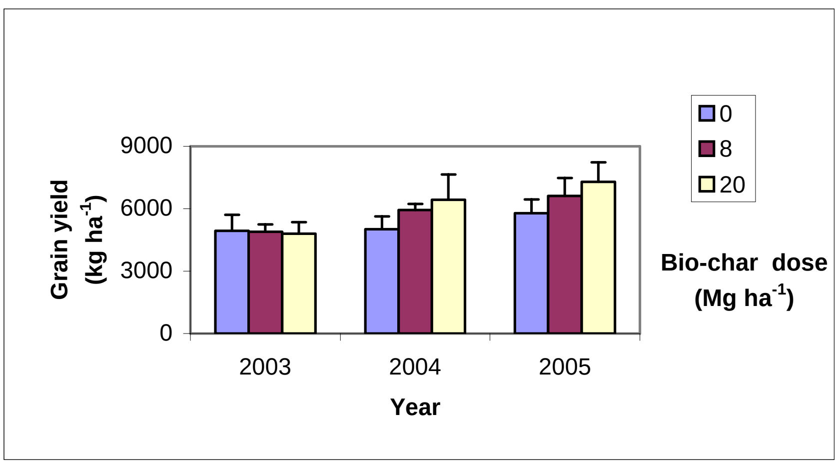

Figure 12. Yields of maize as affected by increasing doses of bio-char in the acid soil savannas of Colombia.

Fluxes of greenhouse gases: The use of bio-char resulted in a net reduction of net annual emissions of nitrous oxide , and also methane from soils as well as net increases in soil carbon. During the initial year, annual methane sinks by soils were increased on average 200 mg $CH_4.m^{-2}$ in all high bio-char plots relative to the controls, while N_2O emissions were reduced on average 15 mg N_2O m^{-2}. Most of the applied C in the bio-char has long residence times in the soil and consequently constitutes a feasible option to store large quantities of C in the soils on the long term. Overall, the use of bio-char results in a net decrease in the integrated Global Warming Potential from the studied soils.

This study indicates that the use of bio-char in acid soils of very low natural fertility is able to increase crop and plant yield and constitutes a valuable tool to increase soil quality of infertile soils. Biochar also constitutes a new tool to mitigate climate change through long term carbon sequestration in soils and net reduction of methane and nitrous oxide emissions from the soils. Currently an economic analysis to assess the financial feasibility of using bio-char as soil amendment is being conducted through a collaboration with the Universidad de los Andes.

Output target 2006

➢ ***Standard methods for BGBD (belowground biodiversity) inventory published***

Published work

BGBD (2005). Standard project methods for the inventory of below-ground biodiversity, BGBD publication, TSBF, Nairobi, Kenya, CD-ROM.
The CSM-BGBD project is carrying out an inventory of below-ground biodiversity in various benchmark areas in seven tropical countries using standard methods. Standard methods were proposed and accepted during the annual meeting that was held in Embu, Kenya, from February 23rd -29th, 2004. In the report of the annual meting these methods are described, also a CD was distributed for internal use within the project. TSBF issued a CD-ROM with the methods not until the beginning of 2005, with the standard methods for the inventory of BGBD. The CD contains the methods for the inventory of Arbuscual Mycorrhizal Fungi (AMF), ectomycorrhiza, Legumenosae Nodulating Bacteria (LNB), macrofauna, mesofauna, fruitflies, nematodes, entomopathogenic nematodes, phytopathogenic fungi as well as the scheme for taking point samples. The CD contains some background articles on molecular techniques for the identification of AMF and rhizobia.

Fátima Moreira and David Bignell (eds), (2005). Standard methods for the assessment of soil biodiversity in the context of land use practices. Report of the Annual Meeting April 2005, Part B. BGBD report series, TSBF-CIAT, Nairobi, Kenya, p. 56;
Jeroen Huising and Peter Okoth (eds.), (2005). Report of the BGB project Annual Meeting April 2005. BGBD report series, TSBF-CIAT, Nairobi, Kenya, p. 289.
The methods referred to above were compiled in a report that was issued as part B to the report of the annual meeting of the BGBD project in Manaus, April 11- 16, 2005. The report is entitled "Standard Methods for the Assessment of Soil Biodiversity in the Context of Land Use Practices". The report contains a number of additions to the earlier manuals, especially the ASB Lecture Note 6B, in terms of the sampling design, the use of Winkler bags for sampling of termites, ants and beetles, added section on the sampling of mesofauna, updated method and reference list of leguminosae nodulating bacteria and added section for phytopathogenic, saprophytic and antagonistic fungi. The report is an intermediate report while the project is working on an official publication on standard methods for the inventory of below-ground biodiversity.

A special session at the annual meeting was dedicated to the standard of methods for inventory of BGBD. Papers presented during that session are included in the report of the annual meeting. The report contains a paper from the BGBD team Côte d'Ivoire on the rapid assessment of the abundance and diversity of earthworm communities in tropical ecosystems, making an argument to include 4 monoliths in the standard sampling procedure. It further includes a discussion on the standard methods for inventory of termites and ants, suggesting the use of Winklers bags, mini monoliths for endogeic ants and semi-quantitative transect, supported by data on sampling efficiency, as standard procedure. Further contribution are on procedures for the inventory of mesofauna, methodology for soil nematode diversity (paramers and indices) and a report on the methodology for the assessment of AMF diversity.

UAS, BGBD/TSBF-CIAT (2005), Proceedings of National Workshop on Evolving Appropriate Methodologies for Economic Valuation of Ecosystem Service of Below-Ground Biodiversity, 12th – 13th May, 2005, UAS, Bangalore, India, p 134.
During the workshop methodological issues regarding the economic valuation of below-ground biodiversity were discussed and a number of case studies were presented. Methodological issues included for example "social use values in the presence of negative externalities". A nice overview of conceptual

and methodological issues was presented by Dr. B. V. Chinnappa Reddy. Case studies reported on related to the economic valuation of on-farm soil organic matter losses due to soil erosion in different agro-climatic zones of Karnataka, to the economic impact of striga as parasitic weed below the ground, or to the impact of sustainable agricultural production techniques on BGBD in rice cultivation. The last contribution at the workshop was on a topic of specific relevance to the BGBD project, namely agricultural intensification, ecological irreversibility and BGBD.

Work in progress

Conservation and sustainable management of below-ground biodiversity; Standard methods for assessment of soil biodiversity in the context of land use practices, editors Fatima Moreira and David Bignell.

The project aims to publish a manual on standard methods. The publication will have contributions from various authors on the following topics:

- Sampling strategy and design;
- Macrofauna with separate sections on macro-arthropods, earthworms, termites, ants, beetles, recording and expressing the data and minimum data sets;
- Mesofauna: Collembolans and mites;
- Nematodes;
- Microsymbionts: *leguminosae* nodulating bacteria;
- Mitcrosymbionts: arbuscular mycorrhizas;
- Phytopathogenic, saprophytic and antagonistic fungi;
- Soil borne pests
- Entomopathogenic fungi and nematodes;
- Land use and land management practices
- Soil structural stability

Output target 2006

- ***At least three indicators of soil health and fertility at plot, farm and landscape scales in hillsides of Africa identified***

Published work

P. Tittonell[1], B. Vanlauwe[1], P.A. Leffelaar[2] and K.E. Giller[2] (2005) Estimating yields of tropical maize genotypes from non-destructive, on-farm plant morphological measurements. Agriculture, Ecosystems and Environment 105: 213-220.

[1]TSBF-CIAT,Nairobi, Kenya; [2]Wageningen University, The Netherlands

Abstract: Maize is the main grain crop grown in the highlands of sub-Saharan Africa, on a broad range of soil fertility and management conditions. Important yield variability has been reported at different scales, reflecting the intensity and spatial distribution of growth-limiting and growth-reducing factors. Maize yield estimation represents a valuable tool to assess within-farm variability in soil fertility through crop performance. The objective of this study was to develop mathematical relationships between plant morphological attributes and grain yield of tropical maize genotypes, based on plant allometric characteristics. These models were used to estimate maize yields and the estimates were validated against independent data collected from experimental and farmers' fields in western Kenya. Three commercial hybrids and three local varieties were considered. Multiple linear regression models including plant height and either ear length or ear diameter as explanatory variables, and simple linear regressions including only plant height, were the most accurate to estimate both total aboveground biomass and grain dry matter yields per plant (r^{-2}.76–0.91). Average values for the harvest index ranged between 0.34 and 0.42, varying with the total aboveground biomass produced per plant. Yield estimations on ground area basis for farmers' fields were acceptably accurate. Plant height measurements can be easily taken at any moment after maize flowering and used in simple models to estimate maize yield. This approach proved also a valuable tool to discuss yield variability with farmers.

Work in progress

Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya

F. S. Mairura[1], D. N. Mugendi[1]; J. I, Mwanje[1]; J. J. Ramisch[2] and P. K. Mbugua[1]

[1]Kenyatta University, Kenya; [2]TSBF-CIAT, Nairobi, Kenya

A study was conducted to determine farmers' perceptions of soil quality and common soil management practices that influenced soil fertility within farmers' fields in Chuka and Gachoka divisions, Kenya. Soils were characterised by farmers after which they were geo-referenced and sampled at surface depth (0–20 cm) for subsequent physical and chemical analyses, to determine differences within farmers' soil quality categories. Indicators for distinguishing productive and non-productive fields included crop yield and performance, soil colour and soil texture. There were significant differences among soil fertility categories, using parametric techniques (ANOVA) for key soil properties ($p < 0.005$), implying that there was a qualitative difference in the soils that were chacterised as different by farmers. Fertile soils had significantly higher pH, total organic carbon and exchangeable cations and available-N. Factor analysis on 15 soil properties identified 4 main factors that explained 68% of the total variance in soil quality. The four Varimax- rotated factors were designated as contrasts that described soil quality status on farmers fields. The first factor grouped calcium, magnesium and soil pH, while the second component comprised of available nitrogen, organic carbon and total nitrogen. The third factor included plant nutrients mainly extractable phosphorus and available nitrogen, while the fourth factor comprised of soil physical properties (macroaggregates, microaggregates, silt, clay). Soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilized spatial heterogeneity and temporal variability in soil quality status within their farms as a resource to maintain or enhance agricultural productivity.

Abundance and diversity of macrofauna and soil aggregates in soil of Central Kenya added with organic material.

A Ponce[1], B Vanlauwe[2], M Pulleman[3], L Brussaard[4], and Dendooven[1]
[1]CINVESTAV, Mexico; [2]TSBF-CIAT, [3]CIMMYT, Mexico; [4]Wageningen University,The Netherlands
Soil fauna play an important role in enhancing and sustaining soil productivity through their effect on soil organic matter decomposition and the resulting availability of plant nutrients and macroaggregate formation. Termites and ants are known to be efficient in digesting cellulose and in some case lignified plant materials. Earthworms ingest plat residues and clay minerals. As a result, their casts often have a higher soil organic matter content (SOM) than the surrounding soil. The objective of this work was to evaluate the abundance and diversity of macrofauna and its effect on aggregates formation and turnover for soils amended with different qualities of organic materials in Central Kenya.

Two experimental sites one in the Embu and the other in the Machanga district in the eastern province of Kenya. A field trial was started at both sites in 2002. The fields were cropped under continuous maize and five different residues with different N, lignin and polyphenol content (*Tithonia diversifolia*, *Calliandra colathyrsus*, maize stover, sawdust and manure). The TSBF methodology was used in macrofauna sampling in two layers 0 – 15 cm and 15 – 30 cm. Dry sieving was done for 5 min over a stack of sieves with a mesh size of 10, 2, 1 and 0.25 mm respectively to separate in five different fractions. Finally, wet sieving was done to dry aggregates (from dry sieving) between 2-10 mm, 1-2 mm and 0.25 - 1 mm aggregates.

Termites, ants and earthworms (ecosystems engineers) were the dominant macrofauna in soil at both sites. At Embu, 62, 10 and 14% of the macrofauna were termites, ants and earthworms respectively. At Machanga, 53, 27 and 3% were termites, ants and earthworms respectively (Figure 13). The addition of manure in the soil had a positive effect on the density of earthworms. Termites were found in all plots. Large densities were found in the plots added with vegetable organic material, with the largest value found in soil added with sawdust. The addition of manure resulted in similar densities for termites as found in unamended soil. The density of ants and "Others" was not significantly different between the plots ($p < 0.05$). The remaining fauna were mainly *Araneae, Acari, Annelida, Blattodea, Coleoptera, Chilipoda, Diplopoda, Diptera, Hemiptera, Orthoptera* and *Pseudoscorpionida*. ($p< 0.05$).

Conclusions: Although termites are the dominant species at both sites, clear effects of organic matter inputs could be seen on both the abundance of termites, ants, and earthworms. Aggregate separation through dry and wet sieving techniques will shed some light on the potential effect of these organic resource-driven changes in the abundance of ecosystem engineers on soil structure and its stability.

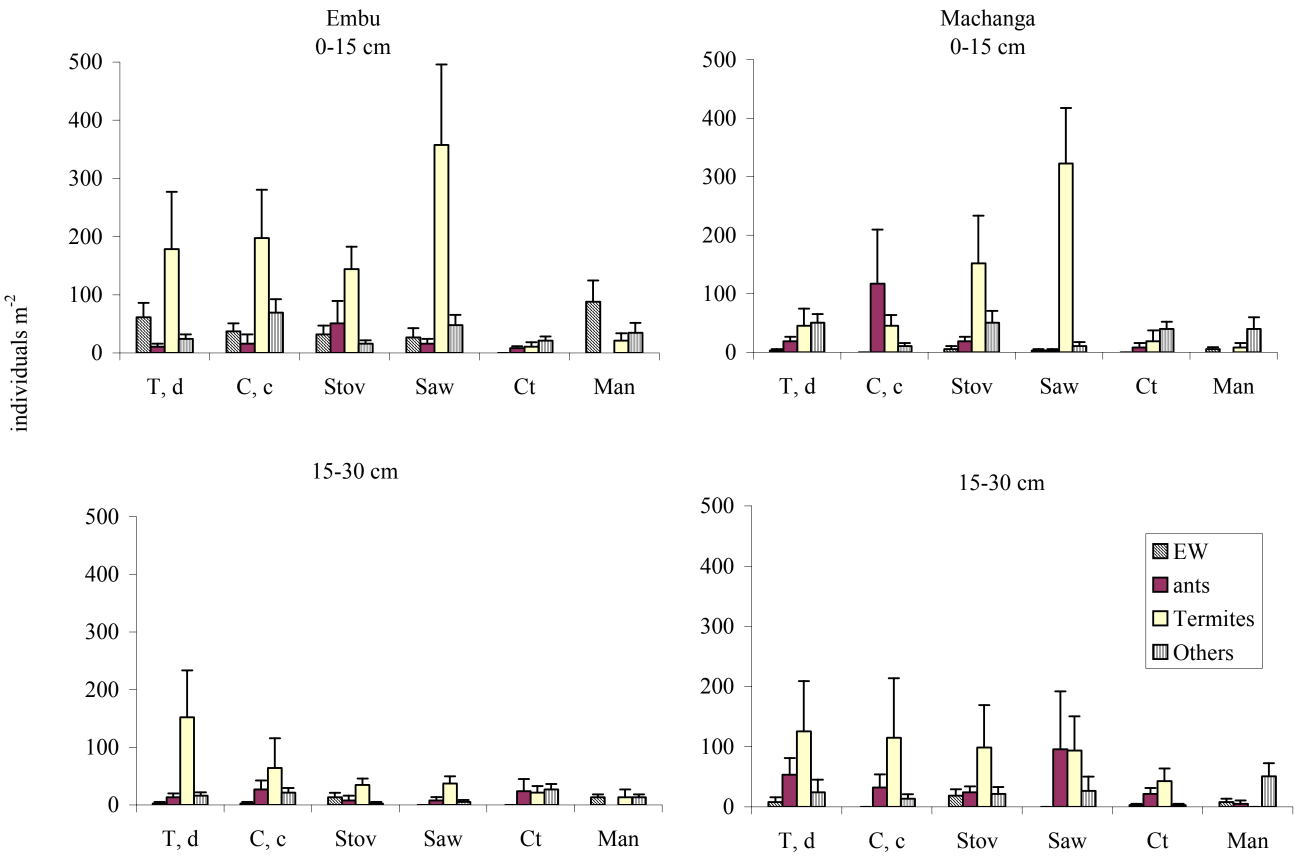

Figure 13. Abundance of specific classes of macrofauna ('EW' means earthworms, termites, ants, and other) in the 0-15 and 15-30 cm of soil at the Machanga and Embu sites. 'T,d' means '*Tithonia diversifolia*', 'C,c' means '*Calliandra calothyrsus*', 'Stov' means 'Maize stover', 'Saw' means 'Sawdust', 'Ct' means 'Control', and 'Man' means 'Manure'. Error bars are Standard Deviations.

Output target 2007

- ***At least three indicators of soil health and fertility at plot, farm and landscape scales in acid soil savannas identified***

Completed work

Soil microbial biomass carbon and nitrogen as influenced by organic and inorganic inputs at Kabete, Kenya

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Soil microbial biomass is the main driving force in the decomposition of organic materials and is frequently used as an early indicator of changes in soil properties resulting from soil management and environment stresses in agricultural ecosystems This study was designed to assess the effects of organic and inorganic inputs on soil microbial biomass carbon and nitrogen overtime at Kabete, Kenya. *Tithonia diversifolia, Cassia spectabilis, Calliandra calothyrsus* were applied as organic resources, and Urea as inorganic source. Soil was sampled at 0-10 cm depth before incorporating the inputs and every two months thereafter and at harvesting in a maize-cropping season. Soil microbial biomass carbon and nitrogen was determined by Fumigation Extraction method (FE) while carbon evolution was measured by Fumigation Incubation (FI) method. The results indicated a general increase in soil microbial biomass carbon and nitrogen in the season with the control recording lower values than all the treatments. Microbial biomass carbon, nitrogen and carbon dioxide evolution was affected by both quality of the inputs added and the time of plant growth. *Tithonia* recorded relatively higher values of microbial biomass carbon, nitrogen and carbon evolution than all the other treatments. A significant difference was recorded between the control and the organically treated soils at the of the season for the microbial biomass nitrogen and carbon dioxide evolution. Both the microbial biomass C and N showed a significance difference ($P \leq 0.05$) in the different months of the season.

Tracing the fate of nitrogen in a humic nitisol under different management practices in Kenya

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[1]*TSBF-CIAT, Nairobi, Kenya;* [2]*Kenyatta University, Nairobi, Kenya;* [3] *Columbia University'USA;* [4]*ICRAF, Nairobi, Kenya;* [5]*National Agricultural Research Laboratories (NARL),Nairobi, Kenya;* [6]*Wageningen University, The Netherlands*

The application of nitrogen in a soil under agricultural production is subject to several pathways including de-nitrification, leaching and recovery by the annual crop. This is as well greatly influenced by the management practices, nitrogen source and soil conditions. The main objective of this study was to investigate the loss of nitrogen (N) through nitrous oxide (N_2O) emissions and mineral N leaching and uptake by annual crop as influenced by the N source. The study was carried out at Kabete in Cetral Kenya. Results obtained indicated that nitrous oxide (N_2O) emissions at four weeks after planting were as high as 12.3 $\mu g\ N\ m^{-2}\ hr^{-1}$ for tithonia treatment and 2.9 $\mu g\ N\ m^{-2}\ hr^{-1}$ for urea treatment. Tithonia green biomass treatment was found to emit N_2O at relatively higher rate compared to urea treatment. However, considering the rate at which N was applied (20 $kg\ N\ ha^{-1}$ and 60 $kg\ N\ ha^{-1}$ for urea and Tithonia respectively), it could be concluded that there was a higher rate of N_2O emission in urea treatment than in tithonia treatment. This was only evident during the fourth week after treatment application.

Soil mineral N content at the end of the season increased down the profile. This was evident in the three treatments (urea, tithonia and control) investigated in the study. Urea treatment exhibited significantly higher mineral N content compared to the control at depth up to 100 cm. This could be attributed to the washing down of the nitrate-N from the topsoil accumulating in the lower layers of the soil profile.

However, there was no significant difference in N content down the soil profile between tithonia treatment and the control. It could be concluded that there was no nitrate leaching in the tithonia treatment. Nitrogen recovery by the maize crop was higher in the urea treatment as compared to tithonia treatment. This was also true for the mineral N content left in the soil at the end of the season.

From this study, it was therefore evident that although there is relatively lower N recovery by maize supplied with tithonia green biomass compared to maize supplied with urea, more nitrogen is being lost from the soil-plant system in the urea applied plots than in tithonia applied plots.

On farm tersting of phosphorus availability from phosphate rocks as affected by addition of local organic resources in Western Kenya

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[1]Moi University, Eldoret, Kenya; [2]TSBF-CIAT, Nairobi, Kenya

Low soil fertility has been identified as the most significant constraint to increased productivity in Western Kenya. Many years of continuous cultivation have resulted in the depletion of native soil fertility and decline in crop productivity. Soils are generally deficient in nitrogen (N) and phosphorus (P). The obvious strategy is the use of inorganic fertilizers and these are recommended by FURP (1994) and the use of low cost technologies or soil fertility improvement such as rock phosphates (PRs). Although PRs are generally insoluble in water it is thought that their solubility and hence availability of P can be enhanced by their incorporation with organic materials. A study on enhanced solubilization of PRs through incorporation of available organic resources including crop residues was conducted. An experiment was conducted between March and August 2004 at Nyabeda on farm site in Siaya district. It was a split plot experiment with three replicates. The main plot units were Minjingu (MPR) and Busumbu (BPR). Both were applied at a rate of 40 kg P ha^{-1} and a similar rate was used for a standard soluble P source of triplesuperphosphate (TSP) for comparison. N was applied at 75 kg ha^{-1}, with 30 kg applied at planting and 45kg as top dressing. Four local organic materials were used at rates of 1 and 2 t/ha. Control and farmers manure was also included. Planting was done using MBILI intercropping system and two crops were used (Soybeans and Maize). The plots were 4.5m by 5m giving an effective area of 13,875 m. Soil sampling was done monthly for available P and pH analyses to determine solubility of PRs with time. Laboratory analyses were done for Olsen P and pH for soils and total P and N in grains and stovers. Data analyses was done using SPSS 12.0 .1 for Windows and means separated using Duncan' Multiple Range Test (DMRT) at 95% confidence. There were significant differences in the main treatments on maize yields. The control was the lowest yielder with mean of 0.18 t/ha while MPR had a mean of 2.46 Mg ha^{-1} and TSP had a mean of 2.03 t/ha. BPR was not significantly different from farmers manure although they were both different from the control. *Tithonia diversifolia* had the highest effect on maize yields with a mean of 2.75 Mg ha^{-1} compared with TSP with a mean of 2.03 Mg ha^{-1}. The rate of 2t/ha was significantly different from that of 1 t/ha in all treatments except for pyrethrum industrial waste and maize stover. TSP gave the highest Soybean yield of 855 kg ha^{-1} and this was significantly different from all others while the control and BPR had the lowest yields of less than 350 kg ha^{-1}. Pyrethrum industrial waste had the best effect on soybean yield with a mean of 608 kg ha while *Lantana camara* had the lowest yield of the organics with mean of 375 kg ha^{-1}. MPR showed good results as there was no significant difference between it and TSP on yield and could thus be used as an alternative source of P. *Tithonia diversifolia* and pyrethrum industrial waste were the most promising organics.

Tillage effects on maize yield in a Colombian savanna oxisol: soil organic matter and P fractions

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Soil organic matter (SOM) is critical to sustainable agricultural productivity in tropical regions, especially in savanna ecosystems. It is an important factor affecting soil quality and long-term sustainability of agriculture. Together with soil management, tillage in particular, SOM influences many physical, chemical and biological properties in highly weathered Oxisols. Oxisols and Ultisols dominate in the eastern plains of Colombia. These soils are infertile and are extensively and traditionally used for cattle ranching, with low management and almost no purchased inputs. Their productivity is consequently very low. However, long-term crop rotation, combined with appropriate tillage, may restore SOM levels that may increase crop yields in Oxisols.

SOM is a source and sink for plant nutrients and plays a key role in the carbon cycle, since it accounts for the major terrestrial pool of this element (i. e. carbon). Organic matter fractionation has been found to increase the sensitivity to detect changes in SOM due to soil tillage and crop rotations. Size-density fractionation enables assessment of labile pools of SOM that are more sensitive to differences in soil management, land use or cropping practices than soil total C. Of practical significance to soil productivity is the fact that SOM is a major source of organic P. In these highly weathered and high P-sorbing soils, P maintained in organic pools may be better protected from loss through fixation than P flowing through inorganic pools.

P is an important nutrient in relatively short supply in most natural ecosystems and is the primary limiting nutrient for crop production in highly weathered tropical soils. The deficiency is mainly caused by strong adsorption of $H_2PO_4^-$ to Al and Fe oxides and hydroxides (sesquioxides), which turns large proportions of inorganic P into a form that is unavailable to plants. However, plants growing in these soils have access to some P fractions (especially the soluble and moderately soluble fractions) that are best estimated by P fractionation procedures such as the one by Hedley. This procedure involves sequential extraction of inorganic P (Pi) and organic P (Po) with increasingly aggressive reagents. This allows characterization of the different pools of Pi and Po that are supposed to be differentially available to plants. Compared with the other major nutrients, P is by far the least mobile and available to plants in most soil conditions, particularly in Oxisols and is therefore likely to be greatly affected by tillage. Mechanical manipulation of soil during tillage may increase the chances of contact between soil solution or fertilizer-derived P and exposed soil particles and this facilitates the formation of stable insoluble P compounds. Tillage, notably ‘no-tillage’, affects some chemical characteristics related to soil acidity that may influence P availability, plant growth and yield. Organic matter and P accumulate in the top few centimeters under ‘no-tillage’ compared with ‘conventional tillage’, which may reduce Al toxicity. Other nutrients also accumulate near the surface in ‘no-tillage’ soils, causing increases in the concentration of electrolytes and P sorption. These effects may offset the benefits of SOM and P accumulation on Al toxicity in ‘no-tillage’ soils.

Recently, interest in long-term experiments has increased worldwide because they are the only means of identifying suitable indicators for early warning of productivity decline and ecosystem damage. Also, long-term data can be used in testing or evaluating predictive models. The objectives of this study were to evaluate the impact of minimum-tillage (reduced harrowing intensity followed by direct seeding), no-tillage (direct seeding) and crop rotation on: a) soil organic matter fractions, b) soil P fractions and c) maize grain yield in a long-term experiment on an acid-savanna soil.

Studies were carried out at the CIAT-CORPOICA experimental station, Carimagua (4°37’N, 71°19’W and 175 m altitude) on the eastern plains of Colombia (Llanos Orientales). The area has two distinct climatic seasons, a wet season from the beginning of March to December, and a dry season from December to the first week of March. The mean annual rainfall and temperature in this area are 2240 mm and 27°C, respectively. Before the beginning of the long-term experiment, the area was under native savanna vegetation (mostly *Andropogon* and *Trachypogon* grasses) and the predominant land use was extensive cattle ranching. Physiographically, the land is generally flat (slope < 5%), typical of the Colombian savanna ecosystem. The soils are deep, have good physical properties but present chemical constraints such as high Al saturation, low organic C, available N and P. They are well-drained silty clay loam Oxisols, and are classified as Isohyperthermic fine-loamy Kaolinitic Tropeptic Haplustox in the USDA soil classification system.

The long-term experiment CULTICORE was established in 1993 to investigate sustainable crop rotation and ley farming systems for the acid-soil savannas. The experimental design was a split-plot with four randomized block as (replications), with main plots assigned to upland rice-based (fertilizer lime) systems and maize-based (remedial lime) systems. Only results for maize-based systems for the cropping year 2001 are reported in this study. This was the seventh rotational cropping after establishment of the experiment, but two years after the implementation of no-till (NT) and minimum tillage (MT) systems. The maize-based system treatments included: a) maize monoculture (MMO), b) maize-soybean rotation (MRT), c) maize-soybean green manure rotation (MGM), d) maize-agropastoral rotation (MAP) and e) native savanna control (NSC) (Table 12). Soybean or green manure rotations occurred within the same year, whereby maize was sown in the first season and soybean in the second season. Pastures were sown simultaneously under maize in 1994 and again in 1998 and were grazed in the intervening 4 years. Native savanna plots were maintained for baseline comparisons and were used as a control to assess the effects of NT and MT on SOM and P fractions and maize grain yield. For the cropped systems, liming was done with 2000 kg ha^{-1} of dolomite prior to establishment of the experiment and maintained thereafter with annual applications of 200 kg ha^{-1}. Each maize crop received 120 kg-N ha^{-1} (split: 40 + 40 + 40), 80 kg-P ha^{-1} and 100 kg-K ha^{-1}. Legumes (soybean or green manure) received 20 kg-N ha^{-1}, 40 kg-P ha^{-1} and 60 kg-K ha^{-1}. Pastures were fertilized bi-annually with 20 kg-P ha^{-1}. The subplots were of size 0.36 ha (200 m x 18 m, 3600 m^2) for maize and soybean, but were 0.72 ha (200 m x 36 m, 7200 m^2) for treatment MAP to allow grazing by cattle and use conventional machinery.

Table 12. Treatment description of the agropastoral/ley farming systems (CULTICORE Experiment, Carimagua)

Treatment	Agropastoral/ley farming system	Description
MMO	Maize monoculture	Maize grown in monoculture; one crop per-year in the first season; second season weedy fallow turned in with early land preparation at the end of rainy season
MRT	Maize-soybean rotation	Maize (1st season) and soybean (2nd season) in 1-year rotation; residues incorporated prior to planting in following season.
MGM	Mayze-soybean green manure rotation	Maize (1st season) and green manure (2nd season) in 1-year rotation. Legumes incorporated at maximum standing biomass levels in late rainy season.
NSC	Native savanna (control)	Managed traditionally by burning annually during the dry season; not grazed.
MAP	Maize-agropastoral rotation	Maize monocrop in year-1; *Panicum maximum* / *Glycine wightii* / *Arachis pintoi* / *Pueraria phaseoloides* pasture sown with rice in year-2; grazed to maintain legume content; rotated every 4 or 5 years depending on pasture composition.

Maize row-to-row and plant-to-plant distances were 80 and 15 cm, respectively. Tillage system NT in this study means that the plots were subjected to conventional tillage (CT) during the first 5-year period and were then sown with a direct drilling sowing machine, herein referred to as direct seeding (i.e. there was no intervention in the soil before planting). Conventional tillage involved use of disc harrows (3-4 passes) for soil preparation before each sowing period. Tillage system MT means that after 5 years of CT, one pass of chisel was done at soil depth of 30 cm during seedbed preparation where the distance between the chisel legs was 60 cm; a harrowing pass was done so as to have a better level of the soil for the sowing of maize and soybean, which were sown with direct-drilling machine (i.e. MT involved reduced harrowing intensity before planting). This means that after 5 years of being cultivated continuously with conventional tillage, the plots were sown with a direct-sowing machine (under both NT and MT), to determine if the cumulative effect of treatments had created suitable soil conditions for a no-till system. Plots under NT would represent the cumulative effect of treatments, while plots under MT would represent an additional improvement of the soil physical conditions.

First results indicate that agropastoral systems under MT generally presented higher H_2O-Po and NaOH-Po values than under NT while for $NaHCO_3$-Pi and $NaHCO_3$-Po the opposite trend was predominant (Figure 14). These observations suggest that tillage treatments differentially influenced biologically available soil P. Inorganic P fractions provided a clearer differentiation among treatments and higher values were generally found in MGM and MRT, while lower values were found in NSC and MAP. Nevertheless, better management options in P cycling likely include those treatments where most of the P is stored in organic form. Under highly weathered and strongly P-sorbing Oxisols NSC and MAP may provide a better protection of P from loss through fixation, as P flowing through inorganic pools is easily fixed as compared to P in organic pools. This confirms our earlier findings indicating that, in highly weathered and P-deficient tropical soils, P availability for plant growth may depend more on biologically mediated organic P turnover processes than on the release of adsorbed inorganic P.

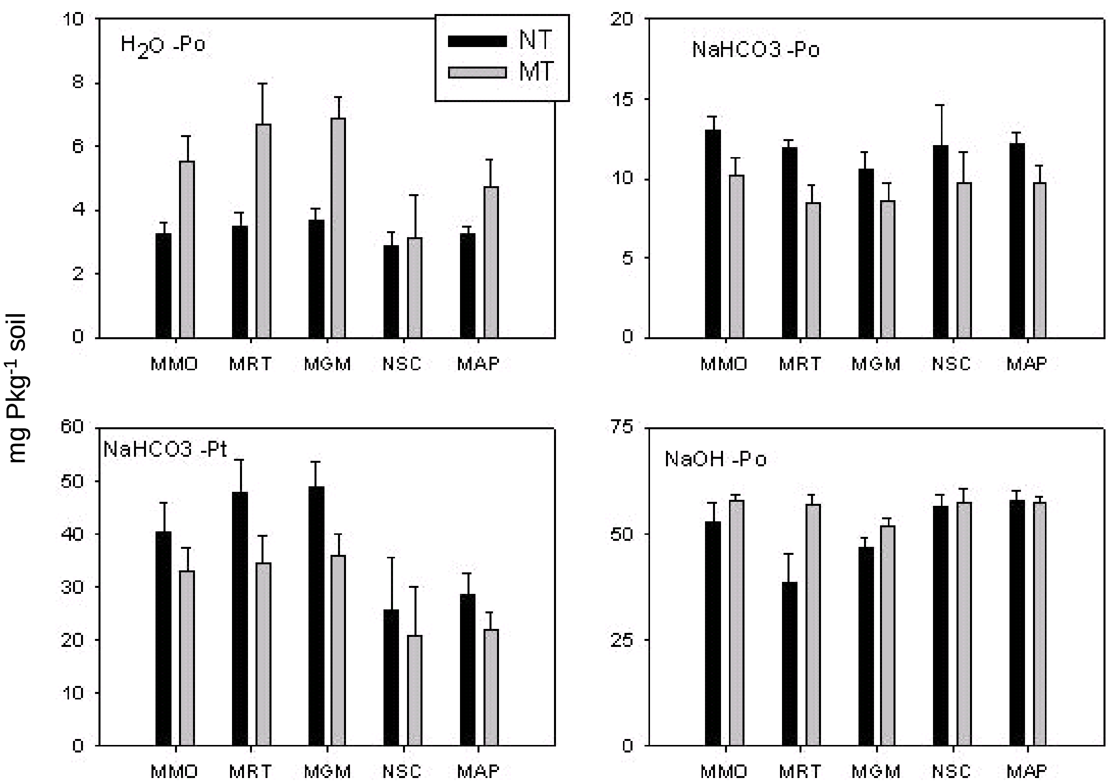

Figure 14. Effect of agropastoral treatments on soil P-fractions of different agropastoral systems. Error bars refer to standard errors of the difference in means.

Output target 2007

- ***Land use intensity impact on BGBD evaluated in seven tropical countries participating in the BGBD project***

Published work

Giller, K.E., Bignell, D.E., Lavelle, P., Swift, M.J., Barrios, E., Moreira, F., van Noordwijk, M., Barois, I., Karanja, N., and Huising, J. (2005). Soil biodiversity in rapidly changing tropical landscapes: scaling down and scaling up. In Biological Diversity and Function in Soils (eds M.B. Usher, R. Bardgett & D.W. Hopkins), pp. 295-318. Cambridge University Press, Cambridge.

Abstract:

1. Habitat modification and fragmentation of remaining pristine areas in the tropics is occurring at a speed that threatens to compromise any serious attempt to assess their value in the biosphere, and catalogue their true biological diversity.
2. Knowledge about the functional significance of soil biodiversity has been strongly influenced by emphasis on temperate climates and by focusing on particular processes of significance to high-input, intensive agriculture. We do not know how robust our methodologies and our concepts are when applied to low-input systems.
3. Links between diversity and function are clearer for functions that are relatively specific, such as the roles of ecosystem engineers, or specific nutrient transformations compared with generalist functions, such as decomposition, micrograzing, predation and antibiosis.
4. Substantial redundancy exists in relation to general functions that could be important for functional stability.
5. When considering the legume-rhizobium symbiosis as a specific case, rhizobial diversity based on molecular phylogeny is only weakly correlated with specific functions such as the ability to form nodules (infectiveness), to fix N_2 (effectiveness) and to survive in the soil (adaptation).
6. Major challenges for the future include developing tools for managing soil biodiversity through manipulation of above-ground vegetation and soil amendments, and understanding the effects of scale to design land use systems for optimal future conservation of the biodiversity of tropical soils.

Towards the end of the year 2004 two of the BGBD reviews were published. The BGBD review of the Kenyan BGBD team was published as a special issue of the **Journal of Tropical Microbiology (Volume 3. Number 1), A Special Issue with Selected Topics on Below-ground Biodiversity in Kenya**". This publication was already reported on in the reported already in the 2004 annual report. The other publication was from the BGBD project Indonesia, though officially published still in 2004, it was not available until 2005 and was therefore not included in the annual report of 2004.

Susilo F.X., Abdul Gafur, MuhajirUtomo, Rusdi Evizal, Sri Murwani and I Gede Swibawa (Eds) (2004) Conservation and Sustainable Management of Below-Ground Biodiversity in Indonesia, Universitas Lampung Bandar Lampung, Indonesia, p 145.

Abstract: The book gives a review of the studies and research done in Indonesia concerning below-ground biodiversity, its importance for agricultural productions and for provision of other ecosystem services. Eighteen contributions from the various authors cover a variety of topics, including the relevance of below-ground and above ground biodiversity, effect of long term conservation tillage and nitrogen fertilization on soil mesofauna and earthworms, the ecological significance of root architecture of drought resistant plants in improving diversity and services of below-ground organisms, apart from

reports on specific organisms, to give some examples. The BGBD review by the Indian team was published in 2005.

Ramakrishnan, P.S., K.G. Saxena, M.J. Swift, K.S. Rao and R.K. Maikhuri (Eds.) (2005) Soil Biodiversity, Ecological Processes and Landscape Management, Oxford & IBH publishing Co. Pvt. Ltd., New Delhi, India, p. 302.

Abstract: The contents are divided into four sections, section 1 (13 chapters) deals with Soil Biodiversity and Ecological Processes, giving the status of research in India on the various group of soil organisms and related processes. Studies indicate that the mega-diversity status of India is reflected swell in its diversity of earthworm species of which 85% are native to India. The high diversity and endemism is explained by the specific geological history of India that as a sub-continent has never submerged through is geological history and the large variety in ecological conditions. The Western Ghats, known as biodiversity hotspot illustrates that high above-ground diversity is translated into a high diversity of earthworms as well. Studies show that land conversion results in loss of endemic species that are not recovered through secondary succession. The conversion of land use is also associated with change in the functional guilds, with increase in epigeic species in agricultural ecosystems.

Castings produced by earthworms may reach up to 140 t/ha and these have generally favorable properties when compared to the soil digested by the earthworms. This is recognized by farmers, many of which are culturing earthworms and use the castings for soil amendments.

As for earthworm, India also exhibits a characteristic and highly divers species composition. The diversity of termite species is directly related to plant/tree diversity. The family of *Termitidae*, which comprises nearly 75% of the known species in the world, has a comparatively poor representation in India. The functional role of termites has not received as much attention as termites as harmful insects to crops, though the beneficial role of termites in providing ecosystem services can be considerable and harmful effects can be mitigated through proper management. Comprehensive contribution on VAM and LNB are also included, the first paper outlining strategies making use of VAM: one is through inoculation techniques and the other through management of indigenous VAM species through agricultural practices.

Section 2 (7 chapters) deals with experimental research related to direct and indirect management of soil biodiversity. One paper shows considerable success obtained with the use of termites for restoring degraded lands, reducing bulk density and increasing soil N and soil C, after introduction of termites using various feeding strategies.

Impressive results have been obtained with rhizobium inoculation techniques in India, with cases reporting up to a 69% increase in yield compared to control. It indicates the potential of this technique; however the results are very inconsistent. Reasons for this inconsistency are discussed and a strategy is suggested to develop cultivars that do not from nodules with native rhizobium as a remedy.

A number of chapters deal with soil organic matter management. One chapter reports rice-wheat systems that no longer respond to increased fertilizer input, which seem to correspond to the decline in OM concentration to very low levels. Solutions are found in integrated use of fertilizer and organic resources and the combination of organic resources like FYM and green manure, through which yields are achieved that cannot be reached with fertilizers alone.

Section 3 (4 Chapters) deals with soil biology and ecology from a landscape management perspective. Chapters describe fallow management under shifting cultivation ion the North-eastern India and with soil fertility management in the BGBD benchmark area in the Western Himalayas that depends on the OM resources being collected for the forest. The sustainability of the system is discussed.

Section 4 provides a synthesis of information arising from sections 1-3 and the process identifying gaps in knowledge and areas of future research and applications. With respect to the inventory of soil biota the synthesis chapter concludes that capacity building in the area of systematics of soil biodiversity deserves urgent attention. Molecular techniques are advocated to be applied to organisms such as bacteria and fungi where morphological taxonomy offers limited scope. As for the soil biodiversity in relation to ecosystem processes it is concluded that the relation between above ground disturbance regime and below–ground biodiversity is still little understood, since the knowledge on the effect of land use change on changes in soil biota is limited. Research is needed to determine thresholds; i.e. what is the minimum number of functional groups to ensure ecosystem resilience. In relation to the importance of soil biota for agricultural productivity it is argued that major benefits could be derived from management of soil biota is in synchronizing nutrient release with crop demand and in controlling pest and disease. The positive impacts of direct and indirect management know from a few experimental set-up needs to be evaluated for different types of agro-ecosystems, and impacts needs to be evaluated in terms of sustainability of higher crop yields in the long run and ecological functions of agro-ecosystems, and socio-cultural acceptability needs to be further evaluated.

In relation to land use and land cover change, the associated management practices, driving factors and ecological and socio-economic implications are know only for isolated pockets. Quantitative information on the impacts of the changes in soil biodiversity and ecosystem function is even scarcer. Spatio-temporal dynamics in above ground and below –biodiversity and their implications need to be studied over a hierarchy of spatial scale – from plot to landscape units of varied sizes and functions. Finally the strength of indigenous knowledge should be capitalized on more effectively, overcoming its weaknesses with appropriate scientific and institutional inputs as an effective way of approaching sustainable development in developing countries.

As already mentioned, all country teams presented mostly preliminary results from the inventory of BGBD during the annual meeting held in Manaus Brazil. The abstracts of the papers presented are included in the report of the annual meeting: **"Proceedings of the Annual meeting 2005, Volume I inventory of Below-ground biodiversity in eleven benchmark areas, within seven tropical countries" edited by E. J. Huising.**

Kerala Forest Research Institute/TSBF-CIAT (2005) Proceedings of the national workshop "conservation and sustainable management of below-ground biodiversity", 21 – 23 June 2005, KFRI, Peechi, Keralal, India, p 621.

Abstract: The workshop included three main sessions. The first session was on theoretical issues concerning belowground biodiversity and review of work done in India. The second session dealt with the various management options and strategies involving BGBD. There were contributions related to vermi-composting, the role of mycorrhizal fungi in maintaining productivity in rice in shifting cultivation systems and use of rhizobium inoculants amongst others. The third session dealt with results from the inventory of BGBD in the three sites that the BGBD project maintains in India, and included site characterization, agronomic practices, inventory of the various functions groups of soil organisms.

Completed work

Soil biodiversity, ecosystem services and land productivity

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Increases in land productivity in the past have largely resulted from the introduction of new crop varieties into farming systems on fertile soils with good supplies of water, fertilizer and pesticides. However, in many less fertile parts of the planet land productivity has actually been declining in the last decades. While high input agriculture has been one alternative to this address this problem, the usually low resource use efficiency of these agricultural systems often leads to high economic and environmental costs. Recent years have shown increasing interest in the development of productive farming systems with a high efficiency of internal resource use and thus lower input requirement and cost. In this context, the importance of soil biodiversity for the improvement of soil fertility and land productivity through biological processes becomes a key component of a strategy towards agricultural sustainability.

The majority of ecosystem processes in both natural and managed ecosystems depend on the soil resource as it not only houses a large proportion of the terrestrial biosphere but also provides the physical substrate for most human activities. Although soils have been widely studied and classified in terms of physical and chemical characteristics, knowledge of soil biodiversity and function is very limited. The role of soil organisms in high input agriculture has received little attention likely because natural and biologically mediated processes like those regulating soil structure, nutrient supply and pest and disease control have been largely replaced by human inputs (i.e. soil tillage, fertilizer and pesticide applications) that ultimately depend on non-renewable energy sources. In natural ecosystems, the internal regulation of function is largely a result of plant biodiversity through flows of energy, nutrients and information, but this form of control is increasingly lost through agricultural intensification. One of the challenges ahead consists on promoting agricultural systems in landscapes managed to sustain rural livelihoods while simultaneously protecting the environment as expressed in the Millenium Development Goals.

Agricultural landscapes hold a large proportion of the world's biodiversity but there is limited understanding about the relative contribution of each management type to conservation of biodiversity, maintenance of ecosystem functions and provision of ecosystem services. According to the Millennium Ecosystem Assessment, ecosystem services can be classified into those associated with the provision of goods (i.e. food, fibers, fresh water), those derived from benefits of regulation of ecosystem processes (i.e. climate regulation, disease control, detoxification), those that support life in the planet (i.e. soil formation, nutrient cycling, pollination) and those cultural services that are not associated with material benefits (i.e. recreation, aesthetic, symbolic).

Soil biodiversity can be considered by focusing on the groups of soil organisms that play major roles in ecosystem functioning through direct or indirect impacts on ecosystem services. Direct impacts are those where specific organisms like symbiotic microorganisms (i.e. rhizobium and mycorrhiza) or pest and diseases (i.e. white grubs and root rots) have a positive or negative effect on crop yield respectively. Indirect effects, on the other hand, include those provided by soil organisms participating in carbon and nutrient cycles (i.e. methanogens and nitrifiers), soil structure modification (i.e. earthworms, fungi and bacteria) and food web interactions (i.e. protozoa and nematodes as microregulators) that generate ecosystem services that ultimately have an impact on land productivity.

Increasing research efforts need to be made to address the challenge of gaining a predictive understanding on the linkages between soil biodiversity, ecosystem functioning and the provision of ecosystem services. Our current GEF funded project entitled 'Conservation and Sustainable Management of Below Ground Biodiversity' that involves research teams from Brazil, India, Indonesia, Ivory Coast, Kenya, Mexico and Uganda is a current effort in this direction that is also addressing the economic valuation of ecosystem services provided by soil biota.

Greater understanding is needed because the adoption of agricultural technologies that rest on the biological management of soil processes driven by soil organisms would greatly depend on identifying creative ways by which farmers "experience" the impacts made by organisms that are not visible to the naked eye by being too small or because they are underground. The 'low profile' of soil biota and associated functions in the provision of ecosystem services has likely been an important factor in their almost complete ignorance in biodiversity conservation and policy development. This problem is particularly critical in tropical areas that are supposed to be the global 'hot spots' of biodiversity in general and of soil biodiversity in particular. Curiously, it is in tropical areas where data and information is most limited.

Work in progress

Environmental and socio-economic characteristics of eleven benchmark areas for demonstration of sustainable management options for conservation of BGBD, E. J. Huising and P. Okoth (eds). Full papers submitted by the seven BGBD country teams are currently being reviewed for inclusion in two project publications. One publication will address the characterization of the benchmark area in terms of soils, land use and socio-economic characteristics. The publication will evaluate and compare land use and land cover change in eleven benchmark areas that each represent eco-regions of global importance, in terms of drivers for the conversion in land use and land cover and considering the threats these conversions pose to below-ground biodiversity.

Loss of below-ground biodiversity as consequence of land use intensification in forest margins of selected biologically highly diverse ecological regions, E.J. Huising *et al.* (Eds). Results of the inventory of belowground biodiversity in the eleven benchmark sites of the BGBD project will be compiled in this publication. The inventory includes a wide range of functional groups of soil organisms, ranging from macrofauna as soil engineers to pathogenic fungi. The change in BGBD will be evaluated against change in land use pattern. Full papers have been received from all country teams covering most of the functional groups. Reviews of the papers have almost been completed.

Characterization of soil macrofauna in the Quesungual agroforestry system of western Honduras

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Agricultural practices that promote increased diversity and abundance of soil macrofauna may improve soil quality and productivity, due to the influence of soil macrofauna on organic matter breakdown, nutrient cycling and soil structure. Southern Lempira department in Honduras is an environment where farmers could benefit greatly from such an increase in soil quality. The landscape is hilly, with steep slopes and shallow soils that are susceptible to erosion. The need for shorter fallow periods, a decrease in the use of slash-and-burn agriculture, and promotion by extension agents has resulted in the large-scale adoption of an agroforestry system known as the 'Quesungual System', based on slash-and-mulch of vegetation, rotation of maize, sorghum and beans and inclusion of diverse trees and shrubs within cropped fields.

This study presents research on the effects of four common land use types (secondary forest, recently cleared agroforestry fields, mature agroforestry fields and silvopastoral fields) in the Quesungual area on soil macrofauna abundance and community composition. The overall hypothesis of the research project is that the Quesungual agroforestry system, through its use of structurally and taxonomically diverse plant species, diverse organic matter inputs, and crop rotation is creating a spatially and temporally heterogeneous soil environment, which leads to multiple niches for soil macrofauna and allows for increased soil biota abundance and diversity.

In August and September of 2004, a set of representative Quesungual agroforestry farms of varying ages (less than two years of continuous cropping, and more than ten years of continuous cropping), silvopastoral farms and fallow sites were chosen. Three farms were included within each category. A transect of 90 metres with a random origin was set up to cover a representative area of the farm, and sampling points were located every ten metres along this transect. Soil macrofauna were sampled at each point using a 'soil monolith' of 25 x 25 x 30 cm, based on standard methodology endorsed by the TSBF. The sample was divided into four layers: litter, 0-10 cm, 10-20 cm and 20-30 cm. The litter and soil samples were hand sorted on site for invertebrates larger than 2 mm, which were preserved in 70% ethanol. In the laboratory, invertebrates were sorted to a broad taxonomic grouping, counted and weighed (a biomass correction factor was applied to preserved weight). In addition to soil macrofauna, at each sample point the tree and shrub component of the vegetation was also quantified. All trees and shrubs within a radius of 5 metres of the sample point were identified, noted as pruned or free-growing (referring to the form of the tree) and the diameter at breast height (1.3 m) recorded.

The four types of land use surveyed differ in the abundance and diversity of tree species. Mean tree densities in relatively new farms (2262 $\pm$ 227 ha^{-1}) were similar to those found in secondary forest (2274 $\pm$ 224 ha^{-1}), while tree density fell sharply in older farms (1053 $\pm$ 114 ha^{-1}) and further in silvopastoral farms (492 $\pm$ 60 ha^{-1}). A similar drop in species richness occurred along the same sequence, from 35.0 $\pm$ 6.4 species per transect in secondary forest, 25.7 $\pm$ 4.3 per transect in young Quesungual farms, to 13.3 $\pm$ 0.8 species in older Quesungual farms and 14.3 $\pm$ 1.8 species per transect in silvopastoral sites (Figure 15).

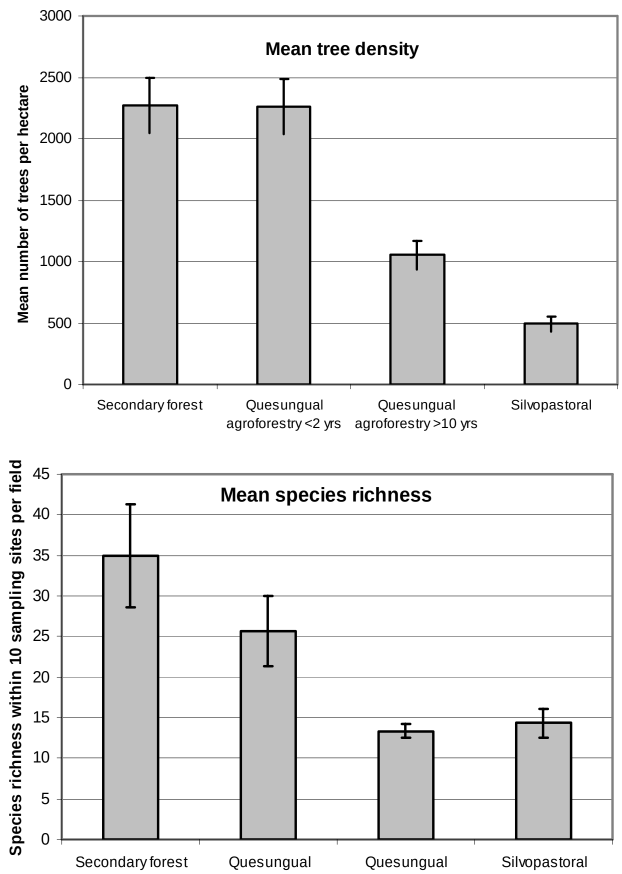

Figure 15. Mean tree density and species richness in each of four common types of fields related to the Quesungual system. Ten samples of tree density within circles of 5 metre radius were taken in three fields for each category. The species richness value is the average of the number of trees found within each of the transects for the three fields surveyed.

During the wet season of 2004, a total of 9673 invertebrates were sampled from the 12 sites with a net biomass of just over 167 grams. There was considerable variation both within and between sites, as shown in Table 13. Highest macrofauna density occurred in younger Quesungual farms, followed by silvopastoral farms, older Quesungual farms and finally fallow sites. Biomass was also highly variable, from a low of an average 2.12 ± 0.48 grams per m^2 at one of older Quesungual fields, to a high of 101.10 ± 24.05 grams per m^2 at another recently cleared field. Biomass tended to be greatest in Quesungual farms of less than two years of age, followed by older Quesungual farms, silvopastoral farms and finally fallow sites.

Table 13. Average abundance and biomass of invertebrates for each of the sites sampled.

Farm Type	Farm Site Name	Av. abundance per m^2	Av. biomass per m^2	N
Quesungual	Young Farm Site 1	814 ± 95	101.1 ± 24.0 g	10
< 2 years	Young Farm Site 2	1152 ± 323	9.1 ± 2.8 g	10
	Young Farm Site 3	2946 ± 916	15.4 ± 4.0 g	10
	All sites	**1637 + 359**	**41.9 ± 11.1 g**	30
Quesungual	Mature Farm Site 1	1586 ± 554	12.5 ± 3.3 g	10
>10 years	Mature Farm Site 2	1112 ± 246	48.7 ± 12.7 g	10
	Mature Farm Site 3	850 ± 355	2.1 ± 0.5 g	10
	All sites	**1182 ± 233**	**21.2 ± 5.6 g**	30
	Silvopastoral Site 1	1510 ± 710	7.3 ± 2.3 g	10
Silvopastoral	Silvopastoral Site 2	2333 ± 887	30.7 ± 7.2 g	10
	Silvopastoral Site 3	682 ± 175	5.3 ± 2.1 g	10
	All sites	**1508 ± 390**	**18.1 ± 3.3 g**	30
Fallow	Fallow Site 1	600 ± 219	13.2 ± 4.6 g	10
(Guamil or	Fallow Site 2	1214 ± 545	12.9 ± 4.2 g	10
2^o Forest)	Fallow Site 3	680 ± 116	9.6 ± 1.6 g	10
	All sites	831 + 199	11.9 + 2.1 g	30

There was also a high degree of variation in the composition of the macrofauna community at each site sampled. Overall, Isoptera (termites) were the most abundant group, making up 50.5% of invertebrates sampled. Hymenoptera (ants) were the second most abundant, at 21.5%, followed by Oligochaeta (earthworms) at 11.8%, Coleoptera (beetles) adults and larvae at 4.9%, and Myriapoda (millipedes and centipedes) at 4.8%. Earthworms in particular tended to be locally very abundant with a patchy distribution, with some sites recording over 400 individuals m^{-2} and others recording fewer than 20 m^{-2}.

The data shown in Figure 16 demonstrate how relative proportions of the major groups vary with land use. For the whole depth of soil and litter to 30 cm, of the three agricultural uses, young Quesungual farms had the highest abundance of most taxonomic groups apart from the social insects. Abundance of litter-dwelling myriapods was highest in secondary forest, and decreased under agricultural use. Conversely, Isoptera consistently increased in number with conversion to agriculture. Oligochaeta were more abundant in Quesungual fields than in either forest or pasture. At soil depths between 10 and 30 cm, the three agricultural uses showed very similar patterns of relative abundance for most groups, although these are notably different from those in secondary forest sites.

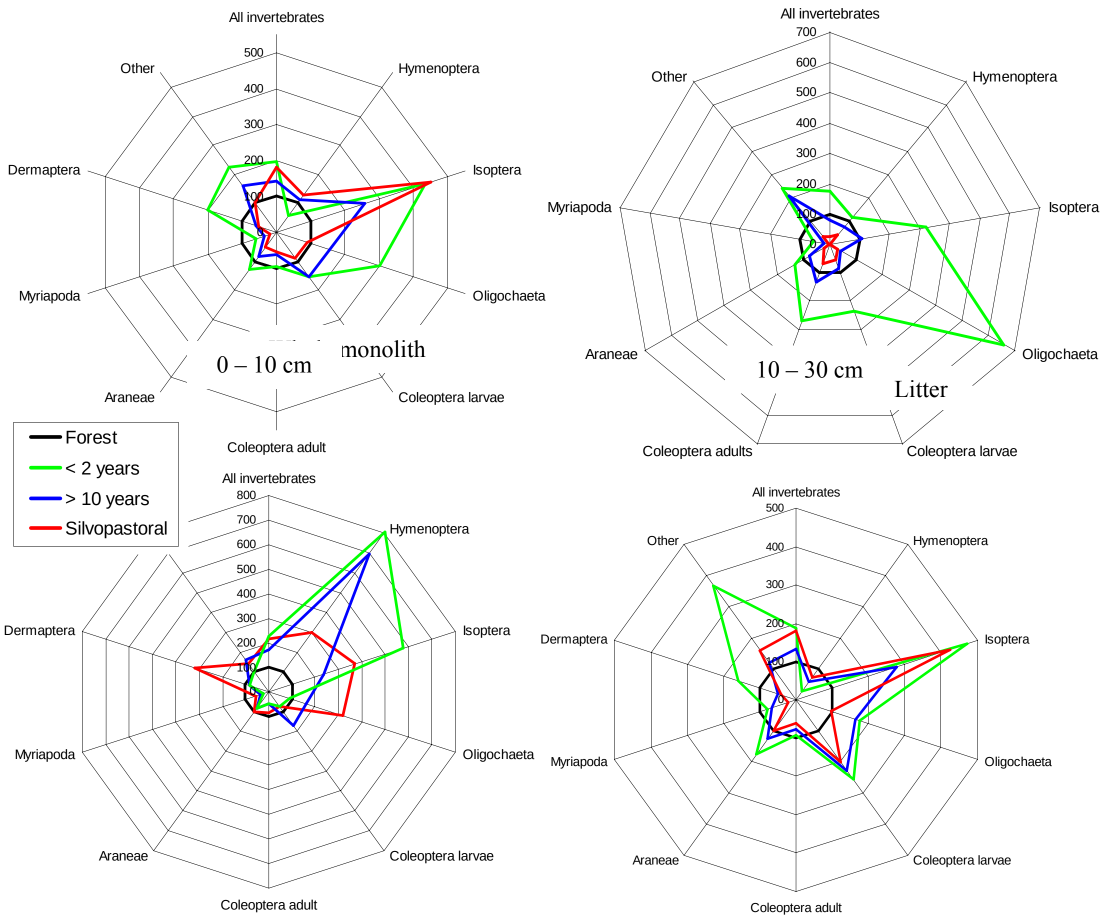

Figure 16. Relative abundance of the all invertebrates and the major groups at varying depths for the four land uses. Abundance in forest sites was taken as 100% and other sites compared to this.

A variety of biophysical factors are likely to influence the distribution of soil fauna, with the result that soil fauna communities are highly variable both within fields, between replicate fields, and between land use types. Despite the highly variable nature of the data, some observations can be made by way of comparing this system with other studied systems. Biomass was not highest, nor was density lowest, under pasture, as expected from previous studies. This may be due to the inclusion of trees within pasture fields, which may not have been present in such high numbers in pasture fields in other studies. It may also be due to the location of pasture fields within a mosaic landscape of agroforestry fields and forest, which may act as habitat refuges for invertebrate populations.

Different ecological and taxonomic groups of soil fauna can be expected to respond in different ways to changes in environmental conditions. Myriapods are consistently reduced in the litter and at all soil depths under agricultural land use, while termites consistently increased in abundance, particularly in agroforestry systems. Ants greatly increased their number in agricultural uses compared to forests in the upper soil, while differences were not as great at other depths. Other studies have also found that myriapod density is significantly affected by land use, and that social insects such as ants and termites increase with cultivation. Both changes are likely to be related to changes in quantity and diversity of organic matter inputs and habitat availability.

The large proportions of individuals present at soil depths between 10 and 30 cm for all land uses was higher than expected, and seems to have been a result of high levels of ant and termite activity at depth in many farms. The dominance of earthworms in the 0-10 cm layer, particularly in pasture sites, may indicate high soil turnover and availability of organic matter at this depth. The decrease in the proportion of litter invertebrates along a gradient from secondary forest through agroforestry and pasture may reflect migration by litter fauna to greater depths as physical protection from environmental fluctuations decreases. The similarities amongst agricultural land uses in the relative proportions of individuals at depths of 10 to 30 cm suggest that community structure and availability of food resources is fairly similar amongst all agricultural uses at greater soil depths.

The greatest challenge facing this study, and the most important in terms of local management of soil biological resources, remains to translate the results of this study and its companion studies into a set of management guidelines that can be used by local farmers to manage soil macrofauna abundance and diversity within their fields, with the goal of improving soil quality and soil fertility.

Local knowledge, soil macrofauna and farm management in the Quesungual agroforestry system of western Honduras

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As part of a broader research program on the functioning of the Quesungual agroforestry system of western Honduras, a study was undertaken of local knowledge of soil fauna and the environmental influences on their distribution and abundance. Little research has been undertaken on local knowledge of soil animals, even though soil fauna can make an important contribution to soil quality through their effects on soil structure and organic matter breakdown. The objectives for this study were two fold: 1) to gain an understanding of the depth of farmers' knowledge of soil fauna, their ecological roles and influences on their distribution; and 2) to better understand local perceptions of soil fauna, so that any management recommendations will be directly applicable.

The local knowledge of farmers practicing Quesungual agroforestry was investigated using semi-structured interviews with 20 farmers in the zone. Interviews were conducted in a conversational manner, and often included a guided tour of the farmer's parcel of land. The objective of the interviews was to understand the values that each farmer attaches to soil fauna and trees as indicators of the quality of the soil, and to find out to what extent farmers recognise changes in the abundance and diversity of soil fauna within their farms (as influenced by factors such as topography, soil, trees), and throughout the year. A further aim was to gain information on farm management practices that could be affecting the abundance of soil fauna within farms, such as the use of fertilizer, pesticides and tree selection.

Earthworms were the most commonly nominated type of soil invertebrate, and were generally regarded as an organism that was beneficial to farm activities. However, all other nominated organisms were generally regarded as having harmful effects on farm activities (see Figure 17). Individual farmers often noted that a particular invertebrate could have both harmful and beneficial effects, particularly in the case of ants. Leaf-cutter ants can inflict substantial crop damage, but at the same time farmers recognise that the discarded material that surrounds the exits to their nests is nutrient-enriched, and often collect this material to aid in the fertilization of high-value crops such as tomatoes.

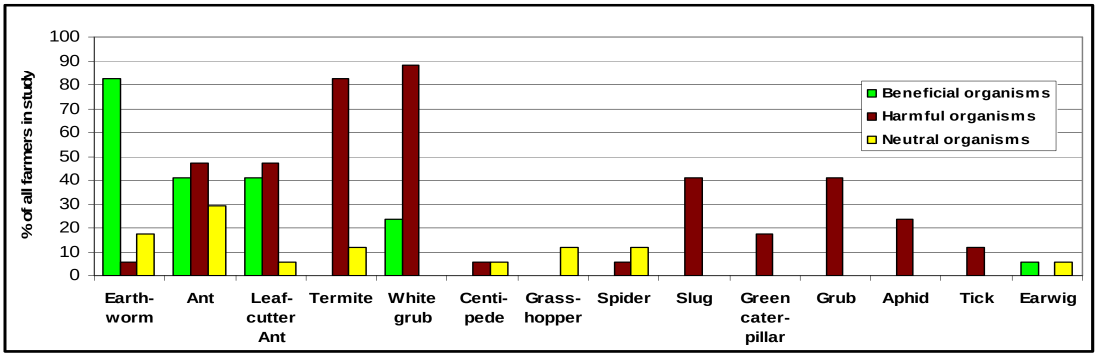

Figure 17. Farmer perceptions of soil invertebrates, Candelaria region, Honduras
Note that not all farmers nominated every type of invertebrate listed here.

Farmers recognized that many different environmental factors could influence the spatial and temporal distribution of soil fauna (see Figure 18). Over 90% of farmers recognized a difference in soil fauna abundance between the dry and wet seasons. Other commonly noted factors were soil fertility status, topographic position in the landscape and type of land use (i.e., pasture, maize crops, fallow). Less commonly noted factors included the presence of trees, shade, surface mulch and animal manure.

Farmers had substantial knowledge of soil fauna diversity and activity in their farms, as well as an understanding of spatial and temporal changes in soil fertility. Factors that farmers considered as important influences on soil fauna were often those that have an influence at broad spatial or temporal scales (season, topography, soil type), while those with a less important influence take effect at a more restricted scale (trees, shade, green manure, animal manure). This finding allows us to construct a hierarchy of environmental factors that have influence at increasingly more detailed scales, which can then be compared to the results of scientific investigations on soil fauna distribution to examine the similarities and differences between the two knowledge systems.

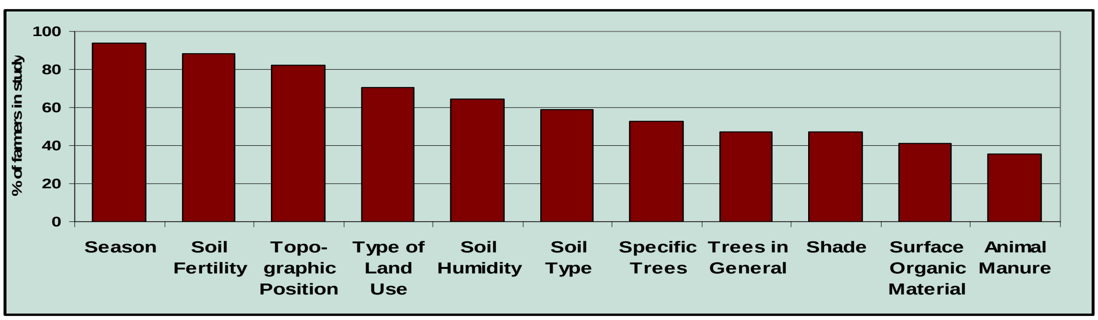

Figure 18. Farmer perception of factors affecting general soil macrofauna distribution.

Similar results were gained from a participatory mapping exercise that was undertaken with a small number of farmers from the region. During a tour of the farm plot, farmers would identify broad zones that were generally good for crop growth or were less fertile due to “static” factors such as soil texture, soil type, aspect or topography, but within each zone, specific areas were identified that for “dynamic” reasons had higher or lower crop yields in that particular growing season, such as high shade cover, high leaf-cutter ant activity or fertilizer shortage.

With regard to management, it is important to note that aside from earthworms, soil invertebrates were generally perceived as prejudicial to farm activities. For example termites, which were highly abundant in farmers’ fields, were generally perceived as harmful because they can damage valuable timber and sometimes feed on ears of corn during the drying process. Small ants often carry away newly planted corn and sorghum seeds but do little harm to established plants. For these reasons, farmers are unlikely to respond positively to management recommendations to augment populations of these animals in their field, but probably would respond positively to measures aimed at increasing earthworm populations.

Spatial dynamics of soil macrofauna: the importance of scale

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In the soil environment, there are many potential abiotic and biotic factors that could influence the spatial distribution of organisms. However, until recently, spatial variation in soil fauna populations was often regarded as random noise in analyses. There has been a flurry of recent research on the spatial distribution of soil fauna, for two main reasons. First, an understanding of the spatial and temporal distribution of soil macrofauna is considered to be important in order to “scale-up” the results of plot-based studies to larger scales, such as catchments, regions and ecosystems. A second area of research focuses around the notion that understanding the spatial and temporal variability of soil macrofauna populations at different scales may be the key to understanding the ecological function of high soil biodiversity, and the interaction between environmental variables and soil fauna.

Agroforestry systems, with their use of diverse crops and over-story trees, present an environment that is highly spatially and temporally dynamic. If changes in above-ground biological resources are important to below-ground biological resources, we should expect that such diversity of vegetation in space and time is reflected in the distribution and abundance of soil macrofauna. This could in turn have important effects on ecosystem function, by creating alternating areas of high and low faunal activity, with resultant effects on organic matter breakdown, nutrient cycling and soil structure.

The “Quesungual” agroforestry system of southern Honduras presents an opportunity for studying the effects of included trees on soil macrofauna dynamics in time and space. Pilot surveys of macrofauna distribution in the region indicated that at a broad scale, soil macrofauna communities are highly variable, and variables such as land use, soil texture or overall vegetation cover were not good predictors of soil fauna abundance. The objective of the current study was twofold: 1) To identify an appropriate scale at which changes in soil macrofauna abundance can be related to environmental variables, and 2) To determine whether trees included within fields exert an influence on soil macrofauna distribution. The eventual goal is to use these results to develop management recommendations for local farmers, so that they may incorporate the beneficial soil macrofauna within their fields.

Since preliminary results indicated that soil macrofauna communities were highly variable within and between farms, it was necessary to stratify the sampling design to take account of variation in broad-scale factors such as topography and soil texture. These factors can have a significant effect on soil macrofauna, principally because of their influence on soil moisture. Two representative farms were chosen, one with a diverse, abundant macrofauna population (Site 1), and one with a very sparse macrofauna population (Site 2). The farms shared similar altitude, geographic location, management characteristics, geology and broad soil type. The farms were stratified using a two stage process. To begin, a map of local soil types and quality was made based on the farmer’s knowledge during a participatory mapping exercise. Second, the soil type / soil quality classes were further divided according to topography (for example, upper-, mid- or lower-slope. The resultant maps contained six distinct zones in Site 1 and five in Site 2. In each of the zones, 20 sample points were located where detailed sampling of biological variables (dry weight of fresh earthworm casts, ant nest density, litter cover) was taken. Single factor ANOVA was used to test differences between the groups. Soil samples to test texture, organic matter content and aggregate stability were taken from 30% of these sites. Further, low-altitude digital aerial photographs will be used to characterise the density and distribution of overstorey trees within each of the zones.

A second set of data was taken at a more detailed scale, specifically to determine the influence of tree location on macrofauna. In each farm, a regular grid of more than 100 sampling points was located in one of the topography / soil class zones. The spacing of the grid points at 2 metres was determined based on the results of a pilot study undertaken 12 months previously. At each point, data was taken on pruned tree abundance, dimensions of free-growing trees, dry weight of fresh earthworm casts, abundance of ant nests, and litter cover. Although statistical analysis is still to be undertaken on this data, there are some strong evident trends which can be presented here in graphic form.

Both farmers identified areas of high and low soil quality within their farm, which were principally related to local classification of soil type. Areas with dark-coloured, loamy soil were generally considered as highly fertile, while areas with yellow- or red-coloured sandy or high clay-content soils were generally considered less fertile, as were areas presenting a high proportion of stones or a hardpan layer below the surface. Topographic position was generally not considered explicitly in farmers' classifications.

Preliminary results of sampling of indicators of soil biological activity lend support to farmers' perceptions. In the fertile Site 1, evidence of earthworm activity was significantly more abundant ($p<0.001$) in zones classified as fertile by the farmer than in less fertile areas with shallow, stony soils or exposed locations (Figure 19). However, litter cover was similar throughout the whole farm. In the lower fertility Site 2, a similar pattern was observed for earthworm casts, with fertile zones recording significantly more activity ($p=0.01$) than low fertility zones (Figure 19). In this farm, litter cover was significantly greater in fertile areas than low fertility areas ($p<0.001$).

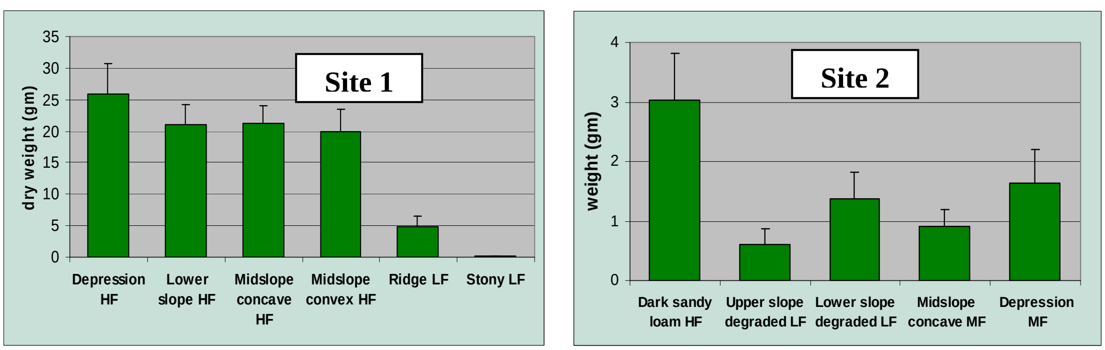

Figure 19: Dry weight of earthworm casts, Sites 1 and 2. HF = High fertility zone, LF = Low fertility, MF = Medium fertility.

Some very interesting results were obtained from the detailed grid survey. In the more fertile Site 1, pruned tree distribution was relatively even over the whole grid area, and litter cover and earthworm casting activity also appear to be relatively evenly distributed. (Figure 20). Ant activity was very low in this farm, while earthworm surface activity was very high. In the less fertile Site 2, pruned trees and free-growing trees were distributed irregularly, with areas containing clumps of trees and some areas containing no trees (Figure 21). There appear to be corresponding changes in litter cover, earthworm activity and ant nest activity. Although relatively even throughout the quadrat, the areas with the lowest litter cover occurred in areas with no tree cover. Earthworm activity appeared to be concentrated beneath pruned trees and tall trees. Ant activity displayed the opposite trend, with nest sites located principally in areas with no trees or low tree abundance.

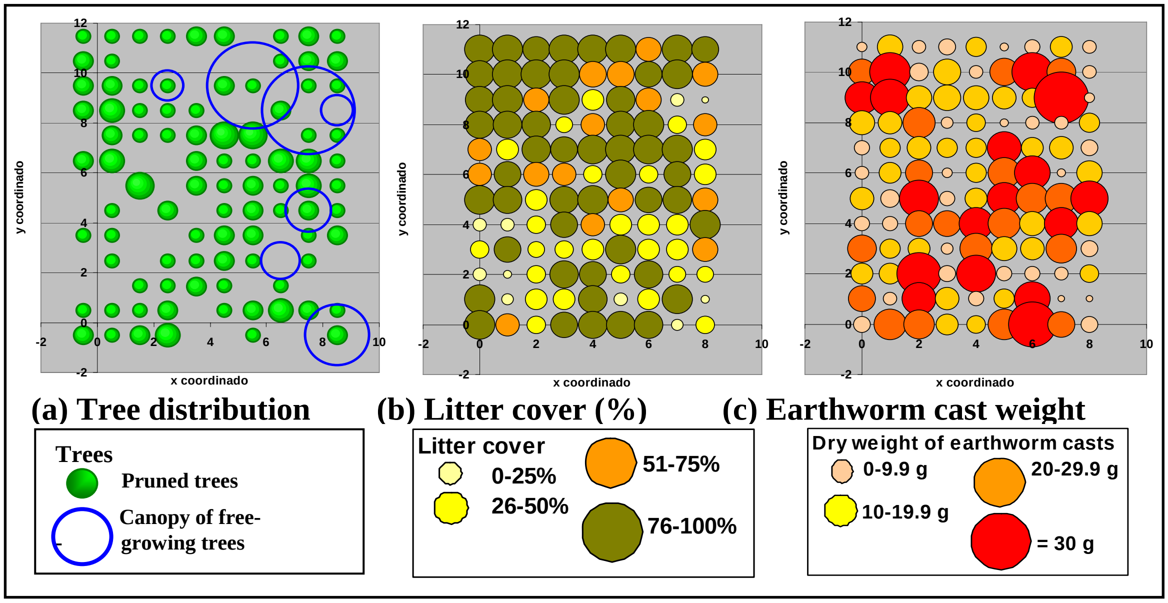

Figure 20. Spatial distribution of selected variables in Site 1 (High soil fertility). Pruned trees are relatively evenly distributed across the plot, with a corresponding even distribution of litter material, much of which is derived from tree prunings. Earthworm cast distribution is also relatively even, although it appears areas with more pruned or large trees tend to have slightly more cast material.

The results of the stratified survey clearly show that differences in topography and soil type within farms affect the activity of soil macrofauna and in some cases, the distribution of farm resources such as litter cover, which protects soils on the steep slopes from soil erosion. At a broad scale, soil macrofauna activity is dependent on soil type (soil texture) and topographic influence. However, at this level of resolution, we cannot determine the more localised effects of trees on below-ground biological resources.

At a more detailed level, once differences in topography and soil type are removed, it is possible to see the influence of trees on soil fauna activity and litter cover. Although results are still preliminary, it seems that the pattern of distribution of trees affects the distribution of other resources. When tree distribution is clumped, we can expect to see a more aggregated distribution of litter cover and macrofauna distribution. However, when trees are distributed more regularly or at higher densities, there is a corresponding more regular distribution of litter cover and macrofauna activity. It appears that pruned trees have similar effects on soil fauna distribution as large trees; thus, farmers do not have to increase the density of large trees (which compete with crops for sunlight, water and nutrients) in order to increase litter cover and soil fauna activity. This research has important implications for farm management, as it shows that farmers can manage litter cover and macrofauna activity by manipulating pruned tree density and distribution.

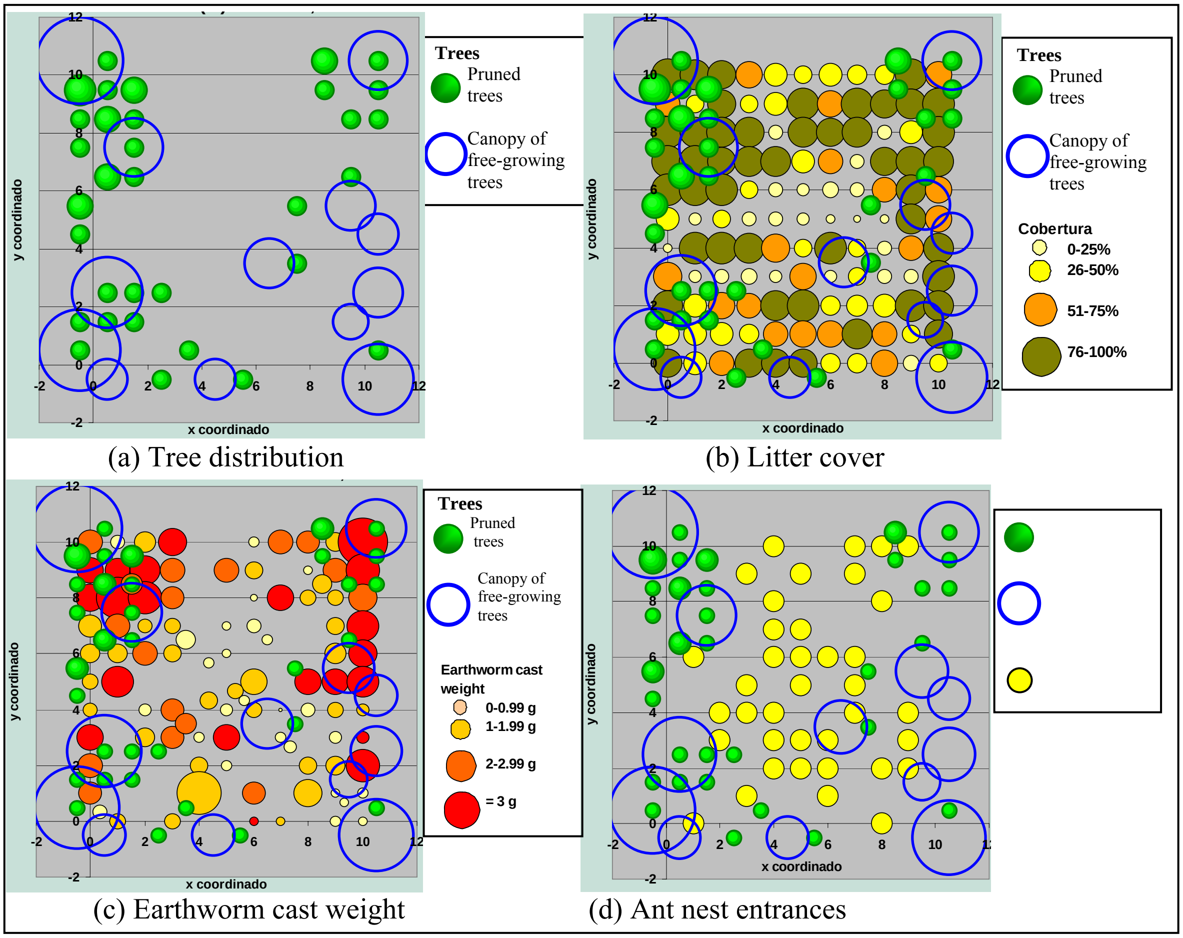

Figure 21. Spatial distribution of selected variables in Site 1 (Low soil fertility). Pruned and free-growing trees display an aggregated pattern of distribution. This aggregation seems to have affected the distribution of earthworm and ant activity, with more earthworm activity beneath trees, and higher ant nest concentrations away from trees. Litter cover also shows a moderate association with tree distribution.

Output target 2007

➢ ***At least two indicators of soil quality used for farmer's decision making in hillsides agroecosystem***

Completed work

Indicators of Soil Quality: A South-South development of a methodological guide for linking local and technical knowledge

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There is increasing evidence that land degradation induced by agriculture has been promoting a gradual shift away from the high input agriculture paradigm, based on overcoming soil constraints with fertilizers, lime, biocides and tillage to fit plant requirements, towards a paradigm with greater reliance on soil biological processes. This more ecological approach is based on adapting germplasm to adverse conditions, enhancing the biological activity of the soil and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use. More recent conceptual developments have led to the emergence of the Integrated Soil Fertility Management (ISFM) paradigm. ISFM is a holistic approach to soil fertility research that embraces the full range of driving factors and consequences - biological, physical, chemical, social, economic and political, of soil degradation. There is a strong emphasis in ISFM research on understanding and seeking to manage the processes that enable change.

Paradigm shifts may allow us to see and understand the world in new ways, but unless their implications are internalized and accepted by farmers they will not yield beneficial impacts through adoption of improved soil management options and healthier landscapes. The limited adoption of new technologies and new cropping systems is now being recognized as closely related to the failure to take into account the local experience and needs of farmers. The limited understanding of underlying causes of ecological change induced by land management creates uncertainties that may also prevent adoption because of perceived high risks. Uncertainty, however, can be reduced by relevant scientific knowledge that integrates local knowledge.

The complementary nature of indigenous and technical knowledge in agriculture has been increasingly acknowledged. While experimental research provides information that can help farmers make better decisions, scientific approaches alone are insufficient for addressing the sustainable management of agroecosystems. The limited success of top-down approaches to management of tropical soils that have excluded farmer insights, has led to an increased recognition that local knowledge is a key resource for the sustainable management of tropical soils.

Farmer's knowledge and scientific knowledge share a number of common 'core' concepts but each knowledge system has gaps that in many cases can be complemented by each other. It is thus argued that research efforts should further explore a balance between scientific precision and local relevance resulting in a "hybrid" knowledge base. It is this expanded 'shared' hybrid knowledge that we are envisioning as the goal of using our methodological approach. The generation of "hybrid" knowledge reflects an effort to understand land management in the context of many forces interacting within a dynamic rural livelihood context.

For farmers and researchers to develop acceptable, cost-effective strategies for improved soil management a common language is required to integrate local and technical knowledge about soils and their management. To facilitate this integration process and make it repeatable, a methodological guide was developed and used in Latin America and the Caribbean. In a South-South exchange of methodology development the guide was further adapted for use in eastern Africa. This guide focuses on identifying and classifying local indicators of soil quality (LISQ) related to permanent and modifiable soil properties, and proposes simple methods that can be used by farmers, extension officers, NGO's, technicians, researchers and educators. This example of South-South collaboration through the transfer of concepts and methodological approaches from Latin America to east Africa has had different implications to different types of partners. Impacts where analyzed in: a) the formal education sector (Makerere University – Uganda), b) a regional research organization (African Highlands Initiative, AHI - Tanzania) and c) a global NGO (CARE-Kenya - Kenya).

This methodological approach is based on the belief that for sustainable soil management to become a reality farming communities require improved capacities to better understand and manage agroecosystem function. Improved capacities of technical officers (extension agents, NGO's, researchers) to understand the strengths and weaknesses of existing local knowledge is also part of the methodology. As limited communication between the technical officers and the local farm community is often a major constraint to capacity building, the methodology deals with ways of jointly generating a common knowledge that is well understood (and "owned") by both interest groups.

Technical indicators of soil quality (TISQ) usually include basic parameters, such as, bulk density, pH, effective rooting depth, water content, soil temperature, total C and electrical conductivity. Local indicators of soil quality (LISQ) are often more variable and include crop yield and vigor, soil color, soil texture and structure, and the presence / absence or abundance of local plant and soil invertebrate species. It should be noted that many LISQ integrate multiple aspects of soil quality in a single indicator and they are much more user friendly than complicated laboratory tests.

Selecting a suitable set of indicators of soil quality (ISQ) is the first step in the conceptual model describing the development of local soil quality monitoring systems (SQMS) in Figure 22. These ISQs are identified from the local and technical knowledge systems and critical levels would need to be defined in order to determine the main soil management limitations of the agricultural system under study. The predominant use of local and/or technical parameters, now part of a common "hybrid" knowledge, varies according to the monitoring objectives; e.g.: greater reliance on local indicators if the users will be primarily farmers, clear linkages between local and technical indicators for extension agents, or integrative technical indicators for policy makers. Attention should also be paid to the inclusion of indicators that can be used while progressively increasing the scale at which results are applied (e.g. from plot to field and farm level, up to watershed, region and nation level). Some examples of such indicators might be crop yield and yield trends, land cover, land use intensity and nutrient balances. More recently, the use of resource and nutrient flows at farm scale to assess land use sustainability and local variation usually missed in studies at higher levels of aggregation (i.e. region, country) has also been proposed by some researchers.

This phase would be followed by the definition of guidelines for the SQMS along with information on interpretation of results. User feedback is very important during this stage because it would contribute to the robustness of the SQMS and thereby should build the grounds for its acceptance. Once the SQMS is fully accepted by users, it can become a Decision Support System (DSS) for management of the soil resource at the farm, village and landscape levels.

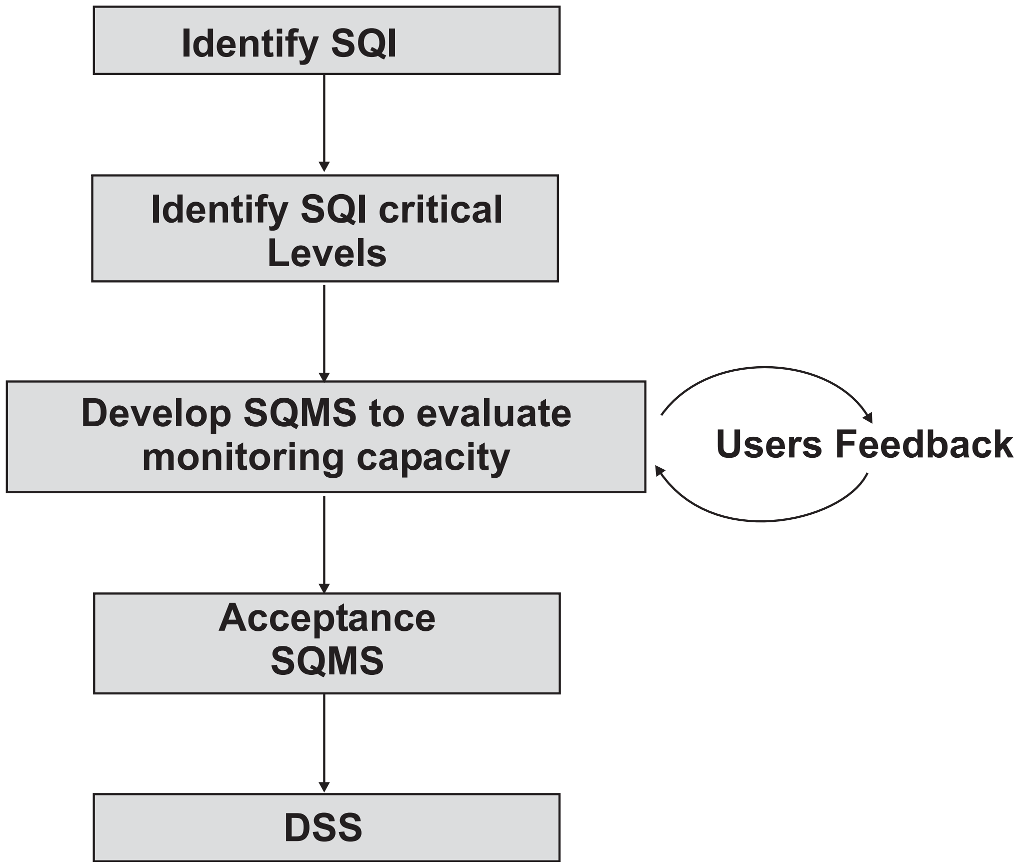

Figure 22. Conceptual model describing process leading to the development of Soil Quality Monitoring Systems

Farmers need early warning indicators of soil quality and monitoring tools to guide soil management because the cost of preventing soil degradation is several times less than costs of remedial actions. Many technical solutions to soil degradation exist but are not adopted because they are developed without the participation of the land user or do not build on local knowledge about soil management. The methodology described here has generated positive impacts on the local knowledge base by providing a way for this tacit knowledge to be widely understood, assessed and utilized, and to be integrated with technical solutions. In addition, local communities have been empowered by the joint ownership of the "hybrid" knowledge base constructed during this process. Action plans developed by local actors through consensus building and new insights derived from the training exercise become the means by which profitable and resource conserving land management are locally promoted and widely adopted.

The South-South cross-fertilization experience provided a unique opportunity to test the hypothesis of convergent evolution, borrowed from natural sciences, in the context of local knowledge systems. The concept of convergent evolution is related to the capacity of natural populations of organisms from distant locations to evolve in similar ways if faced with similar adaptive pressures from their surrounding environment. Our studies of local knowledge systems held by farmer communities in Latin America and Africa suggest that using this concept may be possible for soil quality indicators. Farmer communities studied in Africa (East African Highlands) and Latin America (Central American and Andean hillsides) came from comparable environmental contexts where soil texture (workability), soil depth, soil organic matter (soil color), slope and other common factors played an important role in farmer decision making.

Probably, the most compelling example is associated with the native plants frequently used by farmers as biological indicators of soil quality. In Table 14 we compare rankings of indicator plants conducted by Latin American hillside farmers to characterize quality of agricultural soils with those used by African highland farmers. It is remarkable that quite often the same ubiquitous plants are ranked similarly by farmers in Latin America and Africa as indicators of soil quality (i.e. *Pteridium arachnoideum*, *Bidens pilosa* and *Ageratum conyzoides*) but also that species of the same genus are found in both continents indicating a similar soil quality condition (e.g. *Commelina difusa* and *Commelina africana*). This example also suggests the potential to find useful information at the botanical genus or family level and this would considerably facilitate the wider use of local plants as indicators of soil quality.

Table 14. Native plants as local indicators of soil quality in Latin America and Africa.

	Latin America		Soil Quality		Africa	
Local name	**Scientific name**	**Botanical family**		**Local name**	**Scientific name**	**Botanical family**
Helecho marranero	*Pteridium arachnoideum*	Pteridaceae	Poor	Mashiu	*Pteridium arachnoideum*	Pteridaceae
Mangaguasca	*Braccharis trinervis*	Compositae	Poor	Ma-shuuti	*Philippia usambaresnsis*	Ericaceae
Escoba Lanosa	*Andropogon bicornis*	Gramineae	Poor	Digitaria	*Digitaria sp.*	Gramineae
Siempre Viva	*Commelina difusa*	Commelinaceae	Fertile	Olaiteteyai	*Commelina africana*	Commelinaceae
Papunga	*Bidens pilosa*	Compositae	Fertile	Enderepenyi	*Bidens pilosa*	Compositae
Hierba de chivo	*Ageratum conyzoides*	Compositae	Fertile	Olmalive	*Ageratum conyzoides*	Compositae

Farmers usually manage their soils for short-term maximization of benefits rather than with a longer term perspective of soil resource use optimization. This means that they miss out on the longer-term benefits of ecosystem services. It is thus essential that farmers and other stakeholders in land management, develop greater awareness about the livelihood and income generating opportunities that can be derived from the services provided by natural and agricultural ecosystems like provision of clean water, reduction in soil erosion, increased C sequestration and reduction of greenhouse gas emissions. However, in order for profits to be made from ecosystem services a major change in sustainable natural resource management needs to occur based on much wider adoption of improved land management options.

Work in progress

Assessment of farmers' perceptions of soil quality indicators for crop production within smallholder farming systems in the central highlands of Kenya

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'Soil quality' and 'soil health' are used interchangeably refer to the soils'capacity to support agro-ecosystem function, environmental health, and crop growth and productivity. Due to continuous and intensive cultivation, farmers have experienced declining crop yield over time raising both scientific, and farmer environmental concerns over soil quality. A study was conducted to determine farmers' perceptions of soil quality and common soil management practices that influenced soil fertility within farmers' fields in Chuka and Gachoka divisions, Kenya. Indigenous knowledge and environmental data was collected in face to face interviews and field assessments respectively. Soils were characterized by farmers after which they were sampled at surface depth (0–20 cm) for subsequent physical and chemical analyses, to determine differences within farmers' soil quality categories. Indicators for distinguishing productive and non-productive fields included crop yield and performance, soil colour and soil texture. A total of 18 indicator weed species were used to characterise soil quality. There were significant differences among soil fertility categories, using parametric techniques (ANOVA) for key soil properties ($p<0.005$), implying that there was a qualitative difference in the soils that were characterized as different by farmers. Fertile soils had significantly higher pH, Total organic carbon and exchangeable cations, with available-N being significantly different in Gachoka. Soil fertility and crop management practices that were investigated indicated that farmers understood and consequently utilized spatial heterogeneity and temporal variability in soil quality status within their farms as a resource to maintain or enhance agricultural productivity.

Strengthening "Folk Ecology": Applying community-based learning and communication strategies to improve soil fertility and livelihoods in western Kenya

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This project will study and document the dynamics of how local agro-ecological ("Folk Ecology", henceforth FE) knowledge is generated, shared, or withheld within community-based learning systems. Particular attention will be paid to exploring and understanding which types of learning are considered "convincing" in enriching participants' FE knowledge base as part of their dynamic expertise for agro-ecosystem management. These findings will shape the preparation of appropriate co-learning activities, experiments, and materials to support on-going farmer-researcher dialogue around improving the functioning of the local agro-ecosystems. This strategy will build on Phase One of this project (2001-04) by ensuring that FE can be strengthened through generalizable and repeatable processes rooted in local institutions, actors and processes, satisfying our ultimate goal that the co-learning activities are not inherently reliant on the project.

This project will also focus on how a community-based learning process builds farmers' confidence with unfamiliar concepts and issues, identifying which aspects of complex new knowledge systems can be "scaled up" to wider communities and by which means. We used integrated soil fertility management (ISFM) as an entry point for community activities but – because of the embedded nature of FE – innovations have had broader scope than purely addressing "soil fertility". By identifying and following innovations, we will be able to distinguish which elements are specific to the local context (social / institutional, environmental), and which have more widespread potential. These findings will useful for improving the communication strategies and decision-making abilities of extension, policy-makers, and other research activities addressing agricultural livelihoods in Western Kenya.

Phase One of this project (2001-05) established that communities of western Kenya do indeed possess and use a functioning local ecological knowledge system that we have designated a "folk" ecology to distinguish it from the "formal" or systematized "science" of ecology. This FE has evolved with the local environment to provide locally relevant concepts and understanding of the agro-ecosystem. A community-based learning process helped to make the assumptions and gaps of FE apparent through an iterative dialogue between farmers within farmer research groups (FRGs) and between farmers and researchers (see Figure 23). Making FE more accessible both to its users and to researchers is providing opportunities to improve the utility of local knowledge for making agricultural decisions and to improve the communication of new ideas between actors.

The interactive learning tools developed in Phase One combine anthropological and biophysical science methods to facilitate the exchange of knowledge and skills between farmers, scientists and other agricultural knowledge brokers. This process steadily built on the initial knowledge sets of local communities and outsiders (scientists, extension agents) to integrate the strong points of each knowledge set within a gradually evolving dynamic expertise for managing agro-ecosystems. Making FE more accessible both to its users and to researchers is providing opportunities to improve the utility of local knowledge for making agricultural decisions and to improve the communication of new ideas between actors. The goal throughout has been that FE is strengthened through processes rooted in local institutions, actors and processes, ensuring that the co-learning activities are not (either in perception or reality) overly linked to the presence of the project or of specially trained researchers.

Key outputs

1. Process: Developing more effective tools and methods of communication and dialogue

- Using "simpler" topics as entry points permits long-run empowerment and co-learning.
- Similar "lessons" have inspired very different follow-up activities in the different sites.
- Experimentation and learning on Integrated Soil Fertility Management (ISFM) topics stimulated group empowerment for other topics.

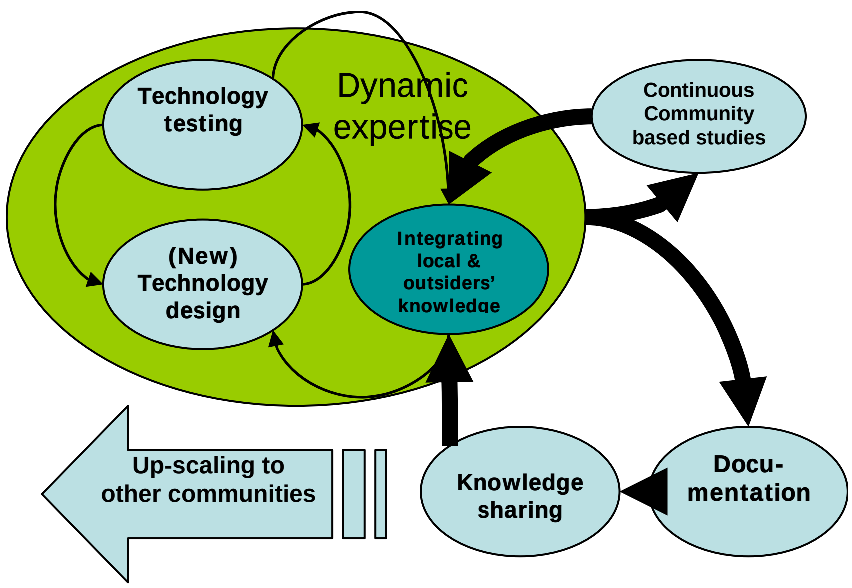

Figure 23 . The "strengthening Folk Ecology" approach. Dialogue and group activities that form part of the "Integration of local and insiders' knowledge" feed into an iterative process of collective and individual technology design and testing, which leads to the generation of local "dynamic expertise" for managing agro-ecosystems. However, understanding the processes that lead to the evolution of this "dynamic expertise" is as important as the expertise itself. Continuous community-based studies inform researchers' contributions to the integrated knowledge activities, while documentation helps both farmers and researchers share knowledge with each other, with other communities (scaling up activities), and with other knowledge brokers.

2. Process: Using innovative tools to strengthen agro-ecological and practical knowledge

- Interactive work built community understanding of previously difficult topics (i.e.: identifying nutrient deficiencies, differences between organic amendments, differences between inorganic inputs, (dis)advantages of rotating cereal and legume crops, different ways to manage local vegetables).
- Farmer-to-farmer instruction appears to downplay the experimentation process and to focus on transferring the "solutions" or "known concepts" that have emerged from the experimentations.
- The salient points of the approaches developed by Phase One, and the learning process that lead to them within our project experience have been synthesised in a preliminary Folk Ecology Manual as a set of guiding principles to be used by non-specialists.
- Farmer groups assisted the research team to generate and refine local brochures on soil ecology that integrate local and outsiders' understanding of the phenomena.
- Community-led initiatives have generated many dramas and poems relating to soil fertility management.

3. Process: Identifying and working with the diversity of institutions and networks

- Advantageous knowledge is preferentially shared within networks and actually denied to others, which contradicts the popular opinion that networks can be counted on to easily disseminate "successful" technologies.
- Collective endeavours are undermined by "individualistic behaviour" and the absence of "traditional" practices that once united communities (rituals like beer brewing or labour sharing).

4. Product: Understand and document local people's agro-ecological knowledge

- Soil ecological knowledge is not universally held or understood. The extremes of knowledge were documented, from the local "specialists" to more widespread "core" knowledge.
- Specific knowledge of soil nutrition was extremely variable but often presented in confusing or incomplete fashion.
- "Easy" techniques for learning and demonstrating soil fertility management concepts are rarely found, and unless farmer-to-farmer instruction is an ongoing process transfer of concepts is rarely possible (i.e.: only of techniques).
- The concepts of soil ecology are embedded within more holistic concerns about crop performance (climate, water, pests, markets).
- Decision-making processes and criteria relating to the allocation of scarce soil fertility management resources were also documented.

5. Product: Comparative analysis of scientific and indigenous agro-ecological knowledge

- Data sets for the community-based experimentation / demonstration activities have been analysed and interpreted with the FRG's to inform their own collective and individual experimentation
- The relevance and comparability of local indicators of soil and compost quality have been addressed in several detailed studies that have been fed back into the experimentation and demonstration processes with the FRG groups.
- Companion work within TSBF has established relationships between the soil fertility gradients identified by soil analyses within farms and the diversity that farmers identify and exploit.
- Divergences between local and scientific perspectives have also been documented on, for example, concepts of resource "quality" and nutrient deficiency.

6. Farmer empowerment

- The number of FRG has grown from five to 12 over 2001-2004. Collective, farmer-led activities grew from one to eight over the same period.
- Women have been active members and leaders of the FRG in all sites.
- Activities diversified from simple demonstrations to more experimental learning, with over 100 individual experiments designed to test and adapt the ISFM technologies.

- Participant observation of key informants and of the functioning of the FRGs demonstrated that FE is learned and modified through a variety of learning styles, and that no single approach is fully sufficient for building farmers' confidence with new or unfamiliar topics.
- The use of a community resource centre in Emuhaya (essentially a "single use" project facility) was a resounding failure and never really used except "for show". Literature and results from farmer research activities were ultimately much better disseminated by farmers themselves through local networks and groups.

7. Knowledge generation and attitude changes with other partners

Findings from the FE project, particularly about the nature and depth of soil ecological knowledge, the utility of plant indicator species in assessing soil quality, and knowledge gaps relating to soil nutrients have fed into TSBF-CIAT proposals since 2002. These include:

- A 2002 MSc thesis *Soil fertility gradients in smallholder farms of western Kenya* (by Pablo Titonell, Wageningen University),
- A broader Rockefeller Foundation supported project *Valuing within-farm soil fertility gradients to enhance agricultural production and environmental service functions in smallholder farms in East Africa* (2003-07), which has co-funding from the Belgian Inter-University Fund.

Attitude changes outside of TSBF-CIAT resulting from exposure to the FE project included:

- TSBF-CIAT's project partners in a GEF-funded project on *Conservation and Sustainable Management of Below-Ground Biodiversity*, have adapted participatory FE approaches for community dialogue into their activities in 7 country sites (Kenya, Uganda, Côte d'Ivoire, Indonesia, India, Mexico, and Brazil).
- Inclusion of discussion of FE topics and methods in soil biology / ecology course taught by Daniel Mugendi at Kenyatta University (2002+), which has prompted increased attention to local knowledge in thesis proposals in the University's Environmental Studies Programme.

Output target 2008

- ***Practical methods for rapid assessment and monitoring of soil resource base status developed***

Published work

P. Tittonell[1], B. Vanlauwe[1], P.A. Leffelaar[2], E.C. Rowe[2] and K.E. Giller[2] (2005) Exploring diversity in soil fertility management of smallholder farms in western Kenya I. Heterogeneity at region and farm scale. Agriculture, Ecosystems and Environment 110: 149-165.
[1]TSBF-CIAT Nairobi-Kenya; [2]Wageningen University, Netherlands
Abstract: The processes of nutrient depletion and soil degradation that limit productivity of smallholder African farms are spatially heterogeneous. Causes of variability in soil fertility management at different scales of analysis are both biophysical and socioeconomic. Such heterogeneity is categorized in this study, which quantifies its impact on nutrient flows and soil fertility status at region and farm scales, as a first step in identifying spatial and temporal niches for targeting of soil fertility management strategies and technologies. Transects for soil profile observation, participatory rural appraisal techniques and classical soil sampling and chemical analysis were sampled across 60 farms in three sub-locations (Emuhaia, Shinyalu, Aludeka), which together represent much of the variability found in the highlands of western Kenya. Five representative farm types were identified using socio-economic information and considering production activities, household objectives and the main constraints faced by farmers. Soil fertility management and nutrient resource flows were studied for each farm type and related to differences in soil fertility status at farm scale. Farm types 1 and 2 were the wealthiest; the former relied on off-farm income and farmed small pieces of land (0.6–1.1 ha) while the latter farmed relatively large land areas (1.6–3.8 ha) mainly with cash crops. The poorest farm type 5 also farmed small pieces of land (0.4–1.0 ha) but relied on low wages derived from working for wealthier farmers. Both farm types 1 and 5 relied on off-farm earnings and sold the least amounts of farm produce to the market, though the magnitude of their cash, labour and nutrient flows was contrasting. Farms of types 3 and 4 were intermediate in size and wealth, and represented different crop production strategies for self-consumption and the market. Average grain yields fluctuated around 1Mg ha^{-1} yr^{-1} for all farm types and sub-locations. Grain production by farms of types 4 and 5 was much below annual family requirements, estimated at 170 kg $person^{-1}$ $year^{-1}$. Household wealth and production orientation affected the pattern of resource flow at farm scale. In the land-constrained farms of type 1, mineral fertilizers were often used more intensively (ca. 50 kg ha^{-1}), though with varying application rates (14–92 kg ha^{-1}). The use of animal manure in such small farms (e.g. 2.2 Mg yr^{-1}) represented intensities of use of up to 8 Mg ha^{-1}, and a net accumulation of C and macronutrients brought into the farm by livestock. In farms of type 5, intensities of use of mineral and organic fertilizers ranged between 0– 12 kg ha^{-1} and 0–0.5 Mg ha^{-1}, respectively. A consistent trend of decreasing input use from farm types 1–5 was generally observed, but nutrient resources and land management practices (e.g. fallow) differed enormously between sub-locations. Inputs of nutrients were almost nil in Aludeka farms. Both inherent soil properties and management explained the variability found in soil fertility status. Texture explained the variation observed in soil C and related total N between sub-locations, whereas P availability varied mainly between farm types as affected by input use.

P. Tittonell[1], B. Vanlauwe[1], P.A. Leffelaar[2], K.D. Shephers[3] and K.E. Giller[2] (2005) Exploring diversity in soil fertility management of smallholder farms in western Kenya II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. Agriculture, Ecosystems and Environment 110: 166-184.
[1]TSBF-CIAT Nairobi-Kenya; [2]Wageningen University, Netherlands; [3]ICRAF, Kenya
Abstract: Strong gradients of decreasing soil fertility are found with increasing distance from the homestead within smallholder African farms, due to differential resource allocation. As nutrient use

efficiency varies strongly along these gradients, such heterogeneity must be considered when designing soil management strategies, aimed at an improved overall resource use efficiency at farm scale. Here, we quantify the magnitude and study the origin of farmer-induced, within-farm soil fertility gradients as affected by biophysical and socio-economic conditions, and investigate farmers' perceptions of such heterogeneity. Farm transects, participatory resource flow mapping, farmers' classification of land qualities, and soil sampling for both chemical and spectral reflectance analyses were performed across 60 farms in three sub-locations (Emuhaia, Shinyalu, Aludeka) representing the variability found in the highlands of western Kenya. Differences between the various field types of a farm were observed for input use (e.g. 0.7–104 kg N ha^{-1}), food production (e.g. 0.6–2.9 Mg DM ha^{-1}), partial C (e.g. -570 to 1480 kg ha^{-1}) and N (e.g. -92 to 57 kg ha^{-1}) balances and general soil fertility status, despite strong differences across sub-locations. Concentration of nutrients in the home fields compared with the remote fields were verified for extractable P (e.g. 2.1– 19.8 mg kg^{-1}) and secondarily for exchangeable K (e.g. 0.14–0.54 cmol(+)kg^{-1}), on average, whereas differences for soil C and N were only important when considering each individual farm separately. Farmers managed their fields according to their perceived land quality, varying the timing and intensity of management practices along soil fertility gradients. Fields classified by them as poor were planted later (up to 33.6 days of delay), with sparser crops (ca. 30% less plants m^2) and had higher weed infestation levels than those classified as fertile, leading to important differences in maize yield (e.g. 0.9 versus 2.4 Mg ha^{-1}). The internal heterogeneity in resource allocation varied also between farms of different social classes, according to their objectives and factor constraints. Additionally, the interaction of sub-location-specific socio-economic (population, markets) and biophysical factors (soilscape variability) determined the patterns of resource allocation to different activities. Such interactions need to be considered for the characterization of farming system to facilitate targeting research and development interventions to address the problem of poor soil fertility.

K.D. Shepherd[1], B. Vanlauwe[2], C.N. Gachengo[2] and C.A. Palm[3] (2005) Decomposition and mineralization of organic residues predicted using near infrared spectroscopy. Plant and Soil 277: 315-333.
[1]ICRAF, Kenya); [2]TSBF-CIAT Nairobi-Kenya; [3]Columbia State University, USA
Abstract: Characterization of decomposition characteristics is important for sound management of organic residues for both soils and livestock, but routine residue quality analysis is hindered by slow and costly laboratory methods. This study tested the accuracy and repeatability of near-infrared spectroscopy (NIR) for direct prediction of in vitro dry matter digestibility (IVDMD) and C and N mineralization for a diverse range of organic materials (mostly crop and tree residues) of varying quality (n = 32). The residue samples were aerobically incubated in a sandy soil and amounts of C and N mineralized determined after 28 days. IVDMD and quality attributes were determined using wet chemistry methods. Repeatability was higher with NIR than the original wet chemistry methods: on average NIR halved the measurement standard deviation. NIR predicted IVDMD and C and N mineralization more accurately than models based on wet chemical analysis of residue quality attributes: reduction in root mean square error of prediction with NIR, compared with using quality attributes, was IVDMD, 6%; C mineralization after 28 days, 8%; and N mineralization after 28 days, 8%. Cross-validated r^2 values for measured wet chemistry vs. NIR-predicted values were: IVDMD, 0.88; C mineralization, 0.82; and N mineralization, 0.87. Direct prediction of decomposition and mineralization from NIR is faster, more accurate and more repeatable than prediction from residue quality attributes determined using wet chemistry. Further research should be directed towards establishment of diverse NIR calibration libraries under controlled conditions and direct calibration of soil quality, crop and livestock responses in the field to NIR characteristics of residues.

K. Tscherning[1,2,3], E. Barrios[1], C. Lascano[2], M. Peters[2] and R. Schultze-Kraft[3] R. (2005) Effects of sample post harvest treatment on aerobic decomposition and anaerobic *in-vitro* digestion of tropical legumes with contrasting quality. Plant and Soil 269: 159-170.
[1]TSBF-CIAT, Cali-Colombia; [2]CIAT-Tropical Forages Project; [3]University of Hohenheim, Germany

Abstract: Legume tissue quality is a key factor for enhancement of feed resources and contribution to soil fertility in mixed crop-livestock production systems. To compare methods used by soil scientists and animal-nutritionists to assess quality of plant materials, three woody tropical legumes with contrasting qualities were used: *Indigofera zollingeriana* Miq. (Indigofera), *Cratylia argentea* Benth. (Cratylia) and *Calliandra houstoniana* (Mill.) Stan. var. calothyrsus (Meiss.) Barn. CIAT 20400 (Calliandra). Plant material of each legume was used either fresh, freeze-dried, frozen, oven-dried (60 ^{o}C) or air-dried in order to estimate extents and rates of aerobic degradation in litterbags on the soil during 140 days and anaerobic degradation in an *in- vitro* gas production experiment during 144 h. Results showed, that aerobic decomposition rates of leaf tissues were highest for Indigofera (k=0.013 day^{-1}), followed by Cratylia (k=0.004 day^{-1}) and Calliandra (k=0.002 day^{-1}). Gas production rates evaluated under anaerobic conditions, were highest for Indigofera (k=0.086 h^{-1}), intermediate for Cratylia (k=0.062 h^{-1}) and lowest for Calliandra (k= 0.025 h^{-1}). Decomposition and gas production rates differed ($p<0.001$) among species. Differences between post harvest treatments were not statistically significant ($p>0.05$). The extent of decomposition was highest for Indigofera (82.5%, w/w), followed by Cratylia (44.6%) and Calliandra (26.4%). The extent of gas production was highest for Indigofera (218.8 ml), followed by Cratylia (170.1 ml) and Calliandra (80.1 ml). Extent of decomposition and extent of gas production were significantly different ($p<0.001$) among species. In contrast to the extent of decomposition, the extent of gas production was affected ($p<0.001$) by sample post harvest treatments. Highest gas production was observed for the fresh and frozen treatments. The forage quality parameters that best correlated with aerobic and anaerobic degradation were lignin+bound condensed tannins, lignin+total condensed tannins/N, indigestible acid detergent fibre (IADF) and *in-vitro* dry matter digestibility (IVDMD). Results showed that differences in decomposition and digestibility were more related to intrinsic plant quality parameters than to changes in tissue quality induced by post harvest treatments. In addition, we found that rate of aerobic degradation of legume leaves on the soil was highly correlated ($r>0.80$, $p<0.001$) to IVDMD and gas production ($r=0.53$, $p<0.001$). These results indicate that plant measurements (IADF, IVDMD and gas production) used to assess forage quality in animal nutrition studies are more rapid and resource saving predictors for aerobic decomposition of tropical legumes than initial plant quality ratios (lignin+polyphenols/N and lignin+total condensed tannins/N) commonly used by many researchers. Furthermore, this study confirms the potential usefulness of IVDMD for screening tropical legumes for soil fertility management.

B. Vanlauwe[1], C. Gachengo[1], K. Shepherd[2], E. Barrios[3], G. Cadisch[4] and C. Palm[5] (2005)
Validation of a resource quality-based conceptual framework for organic matter management. Soil Science Society of America Journal 69: 1135-1145.
[1]TSBF-CIAT (Kenya); [2]ICRAF; [3]TSBF-CIAT (Colombia); [4]University of Hohenheim; [5]Columbia University, USA
Abstract: Organic resources (OR) are essential inputs in tropical farming systems and their decomposition dynamics are related to their quality. A Decision Support System for organic N management (DSS) has been earlier proposed that subdivides OR in 4 classes depending on their N, lignin, and soluble polyphenol contents. To validate this DSS, a 28-day aerobic incubation experiment was initiated with 32 OR, mostly crop and tree residues. The OR contained 0.14 to 5.32% N, 2.5 to 29.5 % lignin, and 0.4 to 14.8% soluble polyphenols. In-vitro dry matter digestibility (IVDMD) ranged from 7 to 82%. After 28 days, CO_2-C production varied between 199 and 905 mg CO_2-C kg^{-1} soil, and mineral N contents between 5 and 109 mg N kg^{-1} soil. Based on N mineralization data, 3 classes of OR were evident: class A with N release > 0, class B with N release = 0, and class C with N release < 0. Criteria to separate those classes were based on the OR N and polyphenol content and cut-off values between the classes agreed well those proposed in the original DSS. For class A OR, N mineralization was related with lignin/N ratio (except for *Gliricidia* residues) and for class C OR with N content. Short-term mineralization data supported the existence of 3 classes of OR instead of 4 originally proposed by the DSS. However, due to the multiple functions OR fulfill, some acting in the medium to long term, it is likely that the original 4-class concept will prevail.

E. Velásquez [1,2], P. Lavelle[1], E. Barrios[2], R. Joffre[3] and F. Reversat[1]. (2005) Evaluating soil quality in tropical agroecosystems of Colombia using NIRS. Soil Biology and Biochemistry 37: 889-898.
[1]IRD-Bondy, France;, [2]TSBF-CIAT Cali-Colombia; [3]CNRS-Montpellier, France
Abstract: Near infrared reflectance spectroscopy (NIRS) analysis was used to discriminate soils of different agroecosystems in Colombia, with different contents and qualities of organic matter chemical and biological properties. Correlations were sought between absorbance's in wavelengths classes as determined by NIRS and a set of variables describing soil quality grouped into three classes: (i) chemical variables (Ca, Mg, K, exchangeable Al, total P, P-Bray II), (ii) organic variables (total C, total N, N-NH^+_4, N-NO^-_3, respirometry and carbon content in different fractions separated by the LUDOX physical methods) and (iii) NIRS variables quantifying the absorptions in the near infrared region separated into 101 classes of wavelength). For each group of variables, a PCA, associated with discriminant analysis, was run. Each class of variables separated the different soil-use systems (***P <0.001) similarly. Co-inertia analyses among the different groups of variables verified the sensitivity of the NIRS in detecting significant changes in the soil chemical and organic composition, as well as in microbial activity. These results show the high potential of the NIRS for evaluating soil quality in large areas, rapidly, reliably and economically, thereby facilitating decision-making with respect to soil management and conservation.

Completed work

This ped is my ped: visual separation and NIRS spectra allow determination of the origins of soil macro-aggregates

E.Velasquez[1], C.Pelosi[1], D.Brunet[1], M.Grimaldi[2], M.Martins[3], A.C.Rendeiro[3], E. Barrios[4] and P.Lavelle[1] (2005)
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Macroaggregation is a highly dynamic attribute of soils that is claimed to have a significant impact on their ability to store C and conserve nutrients. There is growing awareness that the dynamics of aggregate production and destruction over time is important to their function as microsites for C sequestration. The effect of different land use practices on their dynamics at different scales and the combined effects of physical, chemical and biological processes involved, are also of great importance. A major obstacle to understanding macroaggregate dynamics is our inability to identify the origins of the different types of aggregates found in soils, their turnover times and positions within the soil matrix.

We propose here a general methodological approach in which the origin of aggregates separated according to visual criteria could be determined by comparing their specific organic matter signatures assessed by NIRS to signatures of biogenic structures produced by soil ecosystem engineers (invertebrates and roots) living in the same soil. A visual method of aggregate separation derived from the highly detailed Topoliantz et al. (2000) assessment technique is proposed and validated across 61 sampling points regularly distributed across a watershed in Nicaragua and representing crops, pastures, forests, coffee plantations and fallows. Coinertia analyses among soil macroinvertebrate communities and the matrix of soil morphological variables showed highly significant relationships. In Amazonian forest patches and pastures from the state of Pará in Brazil, 75 different types of biogenic structures were collected at the soil surface and on tree trunks (Figure 24) and analysed by the NIRS spectral method. We then verified that biogenic structures produced by a wide diversity of soil invertebrates in ecosystems derived from the rainforest in Eastern Brazil have significantly different NIRS (Near Infra Red Spectrometry) spectral signatures.

Figure 24. Example of different types of soil biogenic structures.

Significant differences were observed among the different types of structures that could be grouped according to their broad phylogenetic origin, with large inter-specific differences. NIRS analyses performed on soil macroaggregates separated by our visual technique and large casts deposited at the soil surface by the earthworm *Andiodrilus pachoensis* suggested that this earthworm is not responsible for production of the bio-organic aggregates that comprise a large proportion on the soil volume in this soil.

The effect of mixing prunings of two tropical shrub legumes (*Calliandra houstoniana and Indigofera zollingeriana*) with contrasting quality on N release in the soil and apparent N degradation in the rumen

K Tscherning [123], C Lascano [1] , E Barrios[2], R Schultze-Kraft [3] and M Peters [1]
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Lack of synchronization between N released from prunings applied to the soil as green manures and crop uptake as well as optimization of protein digestibility for ruminants, remain major research objectives for the selection of multipurpose tree and shrub legumes (MPT) for mixed smallholder systems in the tropics. Prunings of the high tannin, low quality MPT *Calliandra houstoniana* CIAT 20400 (Calliandra) and the tannin free, high quality MPT *Indigofera zollingeriana* (Indigofera) were mixed in the proportions 100:0, 75:25, 50:50, 25:75, and 0:100 (w/w) in order to measure the aerobic rate and extent of N release in a leaching tube experiment, and the anaerobic extent of N degradation in an *in-vitro* gas production experiment.

Parameters measured in Calliandra:Indigofera mixtures were compared to theoretical values derived from single species plant material (i.e. 100:0 and 0:100). Aerobic N release and apparent anaerobic N degradation increased with increasing proportion of the high quality legume (Indigofera) in the mixture (Figure 25). While N release in the soil was lower than theoretical values in the mixture 50% Calliandra/50% Indigofera, this was not the case with apparent anaerobic N degradation with the same mixture. Aerobic N immobilization was more pronounced for the mixture 75% Calliandra/25% Indigofera than for 100% Calliandra and negative interaction was observed with apparent anaerobic N degradation in the mixture 75% Calliandra/25% Indigofera. Plant quality parameters that best correlated with aerobic N release and apparent anaerobic N degradation in the rumen were lignin + bound condensed tannins (r = -0.95 and -0.95 respectively, p<0.001). In addition, a positive correlation (r = 0.89, p<0.001) was found between aerobic N release in the leaching tube experiment and apparent N degradation in the *in-vitro* anaerobic gas production experiment.

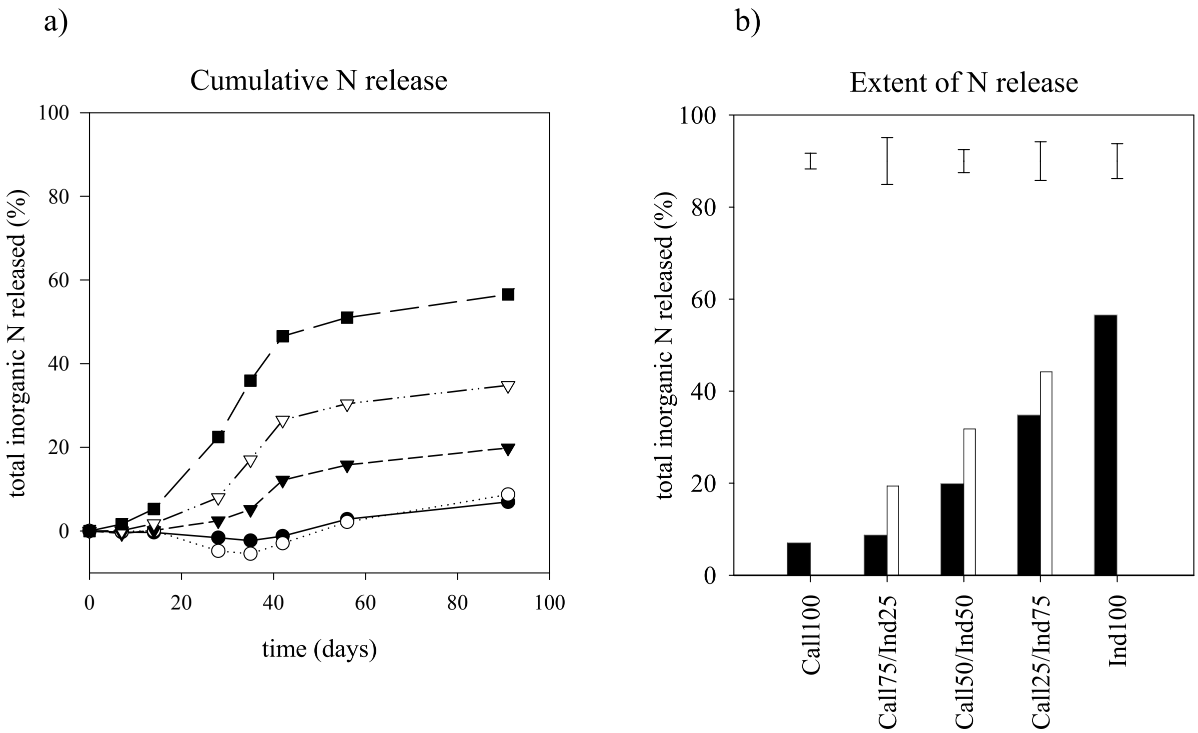

Figure 25. a) Cumulative N release during 91 days of aerobic incubation of Calliandra (Call) and Indigofera (Ind) mixed in the proportions: 100:0, 75:25, 50:50, 25:75, 0:100 w/w and b) extent of N release after 91 days of aerobic incubation of Calliandra (Call) and Indigofera (Ind) mixed in the proportions: 100:0, 75:25, 50:50,25:75,0:100w/w, black bars = measured value, white bars = theoretical value, error bars = standard error of the difference in means. Values are in % of total inorganic N released.

Our results indicate that mixtures of low (low N, high condensed tannins, high fiber concentration) and high (high N, no condensed tannins, low fiber concentration) quality legumes can be utilized to manipulate aerobic N release in the soil and apparent anaerobic N degradation in the rumen of animals. Manipulation of aerobic N release and apparent anaerobic N degradation through mixing of high and low quality MPT can be a useful method to minimize N losses in the rumen and in the soil. The high correlation (r= 0.89, p<0.001) observed between apparent anaerobic N degradation and aerobic N release has cost-saving implications for screening legumes for their green manure potential given the shorter duration required with the anaerobic system.

Work in progress

Adoption potential of improved varieties of soybean in the farming systems of Kenya: ex-ante analysis

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In Kenya, it is common knowledge among the stakeholders in the agricultural sector that soybean [(*Glycine max* L.) Merr.] is not that new in the farming systems, having been introduced as far back as 1904. It is also well known that many development agencies have in the past promoted soybean production in the country. Soybean production in Kenya has, however, remained extremely low and insignificant and does not show up in FAO statistics. Many farmers do not grow the crop and those who grow it plant mostly local varieties (such as *Nyala*, *B. Congo*, *Bossier*, *Duiker*, *Hill*, and *Voster*) that are low yielding with little or no biological nitrogen fixation. Some of the local soybean varieties also need to be inoculated with *Rhizobium* for enhanced yield and many farmers are either not aware of this need or cannot afford the procedure. As a result only few farmers presently grow soybean in the farming systems of Kenya. These few farmers devote only a small fraction of their land and other resources to soybean production. Farmers prefer to give more attention to other legumes especially the common bean (*Phaseolus spp*.) that they are familiar with. Due to the limited attention paid to soybean production by the farmers, the annual production of soybean in Kenya has been estimated at about 5 000 metric tons per annum.

The above abysmal performance of soybean notwithstanding, due to the demonstrated importance of soybean in improving the livelihoods of smallholder farm households and in improving the natural resource-base of many farming systems elsewhere in Africa (e.g., Nigeria, Zimbabwe, and South Africa), some research and development agencies have commenced a new effort at promoting soybean in the farming systems of some East African countries including Kenya. For instance, over the last three years, the Tropical Soil Biology and Fertility institute of the International Center for Tropical Agriculture (TSBF-CIAT) has been conducting on-farm trials (both farmer-managed and researcher-managed) aimed at determining the adaptability and performance of improved promiscuous soybean varieties developed in Nigeria by the International Institute of Tropical Agriculture (IITA) under various farming systems and conditions in Kenya.

Preliminary screening results indicate that over ten of these improved soybean varieties from Nigeria exhibit excellent performance under the agricultural production conditions in western Kenya. Among the other attributes of the improved soybean varieties are their potential to improve soil fertility through more atmospheric nitrogen fixation than *Nyala*, the most popular local variety.

Based on the promising nature of the recent efforts at researching for and promoting improved soybean varieties that are high yielding and soil fertility-improving through their ability to fix atmospheric nitrogen (among other numerous attributes) in the farming systems of Kenya, TSBF-CIAT received financial support from the Rockefeller Foundation to enhance its current effort aimed at promoting soybean in the farming systems of East Africa (Kenya, Uganda, and Tanzania). Following this financial gesture, TSBF-CIAT has been expanding its soybean research especially in the areas of varietal screening and agronomy in order to select and recommend to farmers the best bet of the varieties that are high yielding, high nitrogen-fixing, and adaptable under different conditions in the farming systems of Kenya, Uganda, and Tanzania. TSBF-CIAT is also empowering the farming communities on various methods of processing soybean for home utilization and household cash income – an important step to ensure sustainability.

Since many past projects aimed at promoting soybean in East Africa (including Kenya) region could not result in the take off of soybean, TSBF-CIAT considered it crucial to carry out ex-ante analysis of the adoption potential of the new promiscuous soybean varieties in the farming systems of Kenya, essential before committing scarce resources in promoting adoption and other scaling out and scaling up activities.

The overall objective of this paper is to carry out an ex-ante analysis of the adoption potential of the new improved soybean varieties in the farming systems of Kenya. The specific objectives are: (1) to assess the biophysical, environmental, and agro-climatic conditions of the various farming systems in Kenya in relation to the performance of soybean, (2) to evaluate the attributes of the improved soybean varieties and highlight their important characteristics that will likely influence adoption in the farming systems of Kenya either positively or negatively, (3) to examine the policy environment in relation to the probability of adoption of improved soybean varieties in the farming systems of Kenya, (4) to evaluate the existing institutions in relation to their support or non-support of farmer adoption of the improved soybean varieties, (5) to assess the socio-economic characteristics of the farm households in relation to the probability of adoption of improved soybean varieties, and (6) to determine the potential economic benefits of the adoption of improved soybean varieties in the farming systems of Kenya. All these would help to ensure proper targeting of improved soybean varieties and hence eventual widespread uptake.

Overall, the conditions of the farming systems of Kenya are suitable and can support the adoption of the improved soybean varieties. Eight important broad factors were assessed to reach this conclusion. These are: (i) Biophysical, environmental, and agro-climatic conditions, (ii) Conducive farming practices, (iii) Attributes of the improved soybean varieties, (iv) Political stability and policy environment. Others are (v) Institutions, (vi) Socioeconomic characteristics of farm households, (vii) Economic benefits, and (viii) Farmer participatory approach in improved soybean development and promotion. Across these factors, the potential contributions of improved promiscuous soybean varieties in significantly improving farm productivity have been amply demonstrated. This will most likely attract the interest of the farmers. There is, therefore, sufficient evidence that farmers will likely adopt the improved soybean varieties in Kenya. This ex-ante result indicates that the improved soybean varieties (especially those selected by farmers in different locations) merit further attention and investment.

Determination of the potential of selected legume species and varieties to trigger suicidal germination of *Striga hermontica*

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Striga hermonthica (Del) Benth; a root parasite weed is a major constraint in cereal production in sub-saharan Africa. A single S. *harmonthica* plant can produce as many as 50,000 seeds and remain viable for more than 14 years. Prodigious seed production together with prolonged longevity and special germination requirements makes striga a difficult weed to control. Conditioned striga seeds will only germinate when exposed to synthetic germination stimulant or natural stimulants present normally in the root exudates of many hosts or non-host species. Once germinated, the striga seedling must attach to a host root within 3-5 days or the seedling dies. Hence a sustainable control option for the African resource poor farmers to reduce S. *hermonthica* parasitism is the use of trap crops, particularly legumes that stimulate germination of the parasite seeds but are non-hosts in rotation or intercropping with cereals. However the ability of leguminous trap crops to stimulate S. *hermonthica* seed germination, both between and within species, is variable. The objective of this study was to identify and select in vitro soybean accessions with high ability to stimulate germination of *Striga harmonthic*a seeds.

Roots from thirty-two soybean accessions were tested in laboratory for their ability to stimulate striga hermonthica seed germination. For reasons of comparison, roots of Desmodium, Mucuna, and three maize varieties were included. Strigol and distilled water were used as baseline and control, respectively. Test plants were grown for 21 days after which the roots were harvested and excised into 1cm long pieces. Excised roots (1g) were put in an aluminum foil ring at the center of a petridish lined within a double layer regular filer paper moisten with 5ml distilled water. Glass fibre filter paper disks with conditioned striga seeds were then arranged in four lines to form a cross radiating from the central aluminum ring. Distilled water or strigol was then pipetted over the root pieces in the aluminum foil ring. Petri dishes were then sealed with parafilm, wrapped in aluminum foil and incubated at 30^{o}C for 48hrs. After the incubation period the petri dishes were opened and the number of striga seeds germinated on each glass fibre dish out of the total number of seed son that dish counted using dissecting microscope.

Seeds treated with strigol displayed high germination, which was not significantly different from stimulation due to soybean accessions like TGX1448-2E and TGX1740-2F (Table 15). Seeds treated with distilled water did not show any significant germination (germination % of 0.1%). Soybean accessions were significantly different in their ability to stimulate S.*hermonthica* seed germination with some soybean accessions showing a higher germination potential than Desmodium and Mucuna. Maize variety WH502 was slightly more sensitive, causing higher germination of S.hermonthica seeds compaired to the other maize varieties.

Conclusions: In-vitro techniques show a high variability within the soybean genepool for triggering suicidal Striga germination. This needs to be confirmed in pot and field trials with a selected number of best-bet accessions before specific varieties can be advocated as optimal entry-points in striga-affected areas.

Table 15. *Striga hermonthica* germination percentage caused by roots from 21 days old seedlings in descending order

Species	Variety	%Striga germination
Baseline stimulants	Strigol (GR24)	41.3
Soybean	TGX 1448-2E	38.8
Soybean	TGX1740-2F	38.7
Soybean	TGM76	38.3
Soybean	TGX1876-4E	37.9
Soybean	TGM09	37.9
Soybean	TGX1831-32E	37.0
Maize	WH502	35.9
Soybean	TGX1871-12E	34.2
Soybean	TGM4	33.8
Mucuna	Mucuna	33.4
Maize	Nyamula	33.3
Maize	KSTP94	32.4
Soybean	TGM19	31.5
Soybean	TGX1895-33F	28.7
Soybean	TGX1893-10F	27.9
Soybean	TGX1894-3F	27.1
Soybean	TGX1895-49F	26.7
Desmodium	Desmodium	35.3
Soybean	Namsoy 4m	35.0
Soybean	TGM11	26.4

Species	Variety	%Striga germination
Soybean	J-499	25.9
Soybean	Nyala	25.6
Soybean	Marksoy 1a	25.1
Soybean	TGM93	22.0
Soybean	TGM96	21.4
Soybean	TGM20	20.6
Soybean	TGX1830-20E	19.3
Soybean	TGM60	16.5
Soybean	TGX1898-12F	15.8
Soybean	TGX1895-4F	15.2
Soybean	TGX1893-7F	14.6
Soybean	TGX1844-18E	13.9
Soybean	TGX1895-6F	12.7
Soybean	TGX1869-31E	8.3
Soybean	TGX1878-7E	4.7

Output target 2008

- ***The social, gender, and livelihood constraints and priorities affecting the sustainable use of soils have been identified, characterized, and documented through case studies using innovative methods***

Work in progress

Do farmers "do" soil fertility?

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This paper analyses farming practices among smallholder farmers of Butula, Chakol, Emuhaya and Matayos in western Kenya. It assesses the soil fertility worth of these practices that included use of different organic manures (compost, FYM, mulches) of varying qualities and traditional systems (such as crop rotation, natural fallows, intercropping) that depended on complex local logic. This local logic was not by and large geared toward soil fertility, rather the underlying factors included: available materials; tradition and traditional knowledge; food; economic needs and abilities; land size, labour, new knowledge, and the different interpretations of it, which shaped new dynamism. New dynamism resulted in strengthened ecological knowledge of few local farmers, which nevertheless, did not qualitatively percolate out to other individuals within and outside the sites. This paper points out that accelerating dynamism (i.e. strengthening the positive vitality) of local logic is the best approach to enhance soil fertility management among smallholder farmers of western Kenya.

Whose land degradation counts? Redefining the concept and role of "local knowledge" in soil fertility management

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Land degradation is presented as a major risk for Africa's soils by influential agricultural and environmental studies. Yet technology-driven interventions have failed to stimulate agricultural productivity or to reverse apparent continent-wide problems of soil fertility decline. Soil scientists are therefore increasingly working with multidisciplinary teams and considering the role of local agro-ecological knowledge in natural resource management. This paper uses examples from a community-based learning project in western Kenya to examine how local soil fertility management practices are informed by knowledge generated and refined experientially. This "local" knowledge defines land degradation within a social context and constructs models of soil and soil fertility useful for local livelihood objectives. While the local knowledge of soils is not at risk of commodification as such, scientific efforts to "validate" local soil knowledge in technical terms often backfire by trivialising it, given the embedded and situational nature of soil fertility management knowledge. The paper traces how local understandings of soil types, the nature of soil fertility and land degradation, and of the benefits of organic and inorganic inputs compare with the perspectives of scientists. The western Kenyan example demonstrates that soil fertility managers and researchers must acknowledge the multiplicity and diversity of knowledges operating, evolving, and adapting locally.

Strengthening competitiveness through research: How rural innovations support market-led organic agriculture in Uganda

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As a response to the worldwide demand, certified organic production is increasing rapidly in Uganda. By mid 2005, about 40.000 certified organic farmers produced cotton, sesame, coffee, cocoa, fruits and other commodities for export. Uganda has the fourth largest number of certified organic farmers in the word and is among the top organic exporters in sub-Saharan Africa. In organic farming, smallholders gain from higher product prices and a more sustainable natural resource management, two mechanisms that are aimed at contributing to the United National Millennium Development Goals. Whilst recent developments of the sector have been impressive, there are numerous agronomic, economic and social factors that act as barriers to the further development of organic agriculture in Uganda. The future expansion of organic exports not only depends on the growing export markets overseas, but on pro-organic research that backs organic growers and traders to produce more of what is demanded from the marketplace.

Building farmers' capacities to learn about biological and ecological complexity using participatory approaches and involving farmers in experimentation is a critical success strategy for empowering farmers to be able to learn and to innovate. The purpose of this ongoing research project (2004–2007) is to increase farmers' competitiveness on organic markets by developing and testing ways to forge multi-stakeholder 'learning alliances' at the local and national level. The project is implemented in two pilot sites in western and central Uganda. In each site action research supports farmers in establishing linkages with organic markets. This transition process from traditional to market-led organic production is based on the 'Enabling Rural Innovation' (ERI) approach developed by CIAT.

At each site, the steps in the implementation of this approach for building assets of small-scale organic producers are: (i) participatory diagnosis with the community, with strong emphasis on gender and stakeholder disaggregation, (ii) participatory market analysis to identify market opportunities for competitive and profitable products that farmers are able to produce, (iii) prioritization of opportunities and selection of household food consumption and agroenterprise options disaggregated by gender, (iv) formation of a farmer research group and a market research group to represent the community, and building their capacity to participate in evaluating market orientated and technology options, (v) planning and implementation of experimentation and marketing strategies with farmer research and market research groups, (vi) development of community enterprises and strengthening community Agroenterprise initiatives, (vii) participatory monitoring and evaluation, and learning to derive lessons and impacts, and scaling-up and out of research results and of community enterprise development process, and (viii) feedback of results to the community and identification of further research questions.

Given the potential poverty reducing effects the scientific community needs to re-prioritise research themes and to adhere to a new set of conceptual principles that guide pro-organic research. So far the ERI approach has proven to be useful in facilitating a market-led, farmer-owned, transition process from traditional to organic agriculture as it forges 'learning alliances' between farmers and their research and development partners. Examples will be presented on how this approach has enabled farmers to access new market information (e.g. prices, quantities, quality) and new research products (e.g. disease resistant germplasm, variety evaluation for export, investing in natural resources and soil fertility) on critical aspects of production and how they have used this new information to develop competitive and profitable export organic agroenterprises.

Identifying and overcoming the limitations for implementing conservation farming technology in the Fuquene watershed (Colombia) by integrating socioeconomic and biophysical research with financial mechanisms

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Center (CIP) [4]CIAT Land Use Project; [5]CIAT Impact Assessment Project; [6]Autonomous Regional Corporation for Cundinamarca Province (CAR), Bogotá, Colombia; [7]GTZ - EPC Environmental Program,Bogotá, Colombia;[8]Universidad de los Andes. Bogota, Colombia; [9]Universidad Javeriana. Bogota, Colombia

The Fuquene Lake has been progressively invaded by aquatic vegetation. Nowadays, about 80% of the original lake surface is entirely covered by these plants and some of these parts are fully filled with sediments. Due to the high degree of degradation, the restoration and conservation of this lake has become one of the main objectives for the Colombian environmental authorities since it can affect 27 aqueducts that are supplied by the lake. Regarding this environmental concerns, CAR accepted CONDESAN-GTZ support to conduct research and development actions in order to:

- Identify the point and non point sources of pollutants,
- Prioritize areas according with their responsibility in the lake eutrophication,
- Apply experimental economics methodologies to explore willingness of water users and farmers to cooperate for modifying negative environmental externalities,
- Understand how is the poverty profiles and how are spatially distributed,
- Conduct ex-ante analysis to determine the impact of changing conventional tillage practices by farming conservation practices, and
- Design actions to modify the environmental externalities affecting it.

The environmental and socioeconomic evaluation showed that implementing farming conservation practices in the prioritized areas could reduce the negative environmental externalities by about 50% as the net income and employment opportunities are increased.

In spite of GTZ (EPC)-CAR have been working jointly in the extension of conservation farming practices and adjusting the required equipment to implement direct drilling and reduced tillage, the adoption of this technology was still incipient. The economic games applied in the field demonstrated an important potential of collective action to achieve technological changes. Specifically, about 80% of potato and cereal farmers invited to the games were willing to implement conservation farming practices. On the other hand, water users are willing to pay to upstream farmers as an incentive for promoting sustainable land management if there is a direct negotiation and not the interference of the environmental authority. Thus, collective action for providing better environmental services highly depends on the possibility of negotiating among those actors and on their awareness of the relationship between land use and hydrological externalities.

Although, production costs and productivity surveys showed that by incorporating farming conservation practices the net income is increased, the technological change is not reached readily since it is required an initial investment higher than with conventional tillage since it is necessary the introduction of green manures prior to the conventional crop is sown. Then, to increase the adoption of the technology, the project has been promoting a financial mechanism. The mechanism was created to investigate if the suspected restricted financial capacity of small farmers was constraining a massive technological change in the watershed. To reach this objective CONDESAN-GTZ (AWP) make an agreement with GTZ(EPC)-CAR to assure the technical assistance needed for the implementation of the practices. Also, two farmers associations were introduced to the partnership acting as direct beneficiaries of the financial mechanism and also as intermediaries between CONDESAN and the smallest farmers who do not belong to the associations.

The financial mechanism consists in providing credits to the two farmers associations that were committed to distribute the funds to their associated farmers that are willing to incorporate conservation farming practices. The mechanism was initiated in 2004 and since then, it has made significant progress in two phases. In the first phase a fund was created by CONDESAN-GTZ and managed directly by the farmers associations. The fund resources were used as capital for credits with a low interest rate. As a result, in 100 hectares minimum tillage and green manures were incorporated. However, it did not necessarily reach the target population that is the poorest farmers of the watershed and the available project funds were not enough to respond to the current demand. For this reason a second phase was designed.

In the second phase (2005), a strategic alliance was built with FINAGRO (The National Fund for Financing Farming) in order to facilitate the incorporation of small farmers to the financial sector. In particular, the project funds have been used as guarantee of the 20% of the farmers contracted debt. The resources are deposited in FINAGRO, who guarantees the rest of the debt and provide the credits. In this strategic alliance, CIAT is committed to certify that any Fuquene farmer benefited with the FINAGRO credits for conservation agriculture, are implementing the technology properly. Also, CIAT should demonstrate the impact of conservation practices on the watershed environmental services.

With the new scheme developed in the second phase, CONDESAN- GTZ aims to multiply the existing resources for investment and also, to provide incentive for the use of existing governmental guarantee facilities that are not widely used by the small farmers. This is because of: 1) the lack of commercial banks willingness to lend money to producers that can not offer their own guarantees and 2) the lack of motivation of the farmers to apply for FINAGRO guarantees due to the transaction costs and the time needed for the preparation of requirements and the respective approval. With the guarantee fund provided by CONDESAN-GTZ, the process for accessing to this guarantees and credits is accelerated as the farmers are supported now with resources deposited directly in FINAGRO. This is the first case in Colombia where conservation farming is accepted for receiving guarantees and credits from the financial system. To make this possible FINAGRO is adjusting its credit schedules because from now on it has to include the additional time needed to sow green manures before a commercial crop is established.

These development actions are not only promoting technological changes but are creating in situ research scenarios for investigating the real constraints for using the soils in a sustainable manner. Therefore, CONDESAN-GTZ expects to determine the biophysical ex-post impact of these practices on the soils and lake conditions and the social and economic benefits caused by the technological change. If the results are positive, these practices will be incorporated as an alternative that can be compensated by a payment for environmental service scheme also promoted by the project.

The use of stable isotopes for identifying the sources of Nitrates and Phosphates in Fuquene Lake

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One of the key elements in devising payments or compensation schemes for environmental services is the thorough knowledge about the environmental service itself and the changes or modifications this is facing. This is the case for the water quality of Fuquene Lake in Cundinamarca, Colombia. The lake is suffering with eutrophication due to the incoming loads of nutrients from urban and agricultural activities. Nutrients such as nitrogen (N) and phosphorous (P) are carried in sediments, urban wastes and leached fertilizers. To tackle this problem, researchers were asked about methods to clarify the origin and quantities of pollutants. The use of stable isotopes was sought as one of the strategies in parallel with standard monitoring and modelling techniques. We present a short summary of progress in the use of stable isotope methodology.

In order to have a better understanding of the historical and current status of water resources in the zone, data from previous studies were collected. Data were collected from the National Geological Institute (INGEOMINAS, Instituto Nacional de Investigaciones Geologico-Mineras), Regional Autonomous Corporation (CAR, Corporacion Autonoma Regional), National Geographic Institute (IGAC, Instituto

Geografico Agustin Codazzi) and the National Institute of hydrology and environmental studies (IDEAM, Instituto de Hidrología, Meteorología y Estudios Ambientales). The collected data consisted of water quality measurements on specific locations at different points in time. These different sources were analyzed and when required integrated using different modeling techniques. L-Thia, SWAT and logistic regression models were used to estimate the location of sources. The produced outputs were used to guide water-sampling campaigns in 2004 and 2005 either for stable isotopic and standard measurements. Portable monitoring devices were used in the field and validated with standard laboratory techniques using an atomic absorption spectrophotometer. Isotope results were used to identify the location and type of source and standard measurements to estimate the volumes of different locations. With the delimitation of contributing areas it was also possible to identify the predominant land uses in each contributing zone.

Different techniques and methods have been used by different organizations at different times. This situation generates lack of consistency and reduces the possibility of using the data in an integrated way. There is no simulation method that can use this data as a validation set. Probabilistic methods could be used but their results are restricted to the sampled sites, which in this case do not cover the whole study area.

In spite of the differences among studies, the studies report similar places contributing the most. Such is the case of Tausa and Cucunuba surroundings, which are located at the south of the study region where part of the charcoal mines is also located. Potato farms are also very common in the upper part of Tausa (Figure 26).

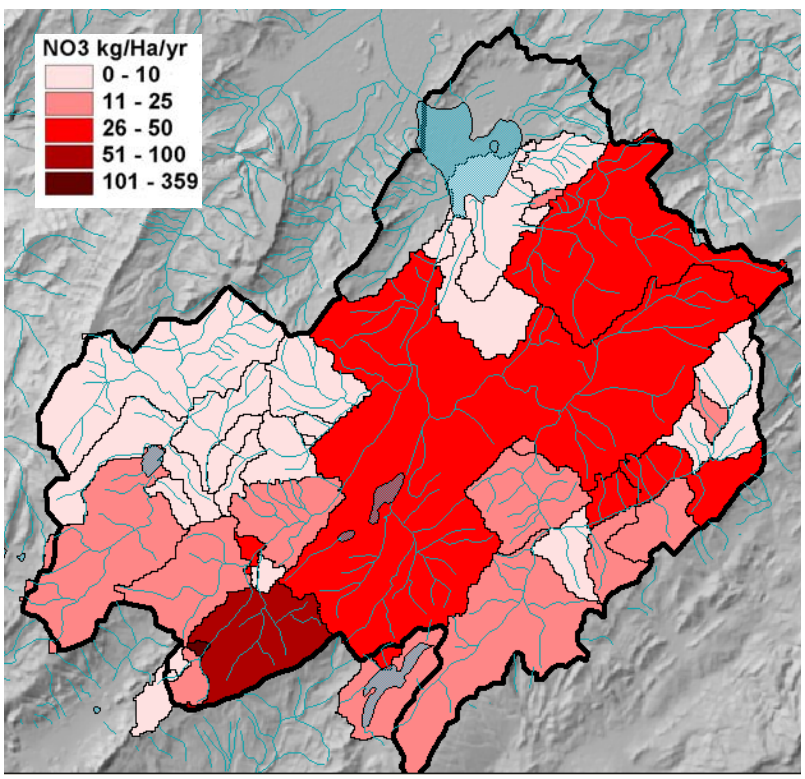

Figure 26. Ten years average total nitrate contribution in kg ha^{-1} considering the nitrate concentrations found in 2005 sampling made by CIAT.

Based on the use of stable isotopes (Figure 27), the discrimination of sources allows us to assign to the sediments the higher contribution source of nitrates with a value of 43.6% followed by fertilizers with 38.3% and organic wastes with 18.1%. Summing up the three sources, pasture area is contributing with 17.4% while cropland is accounting for the 43%. Nitrates attached to sediments are accounting for more than a half of cropland contribution.

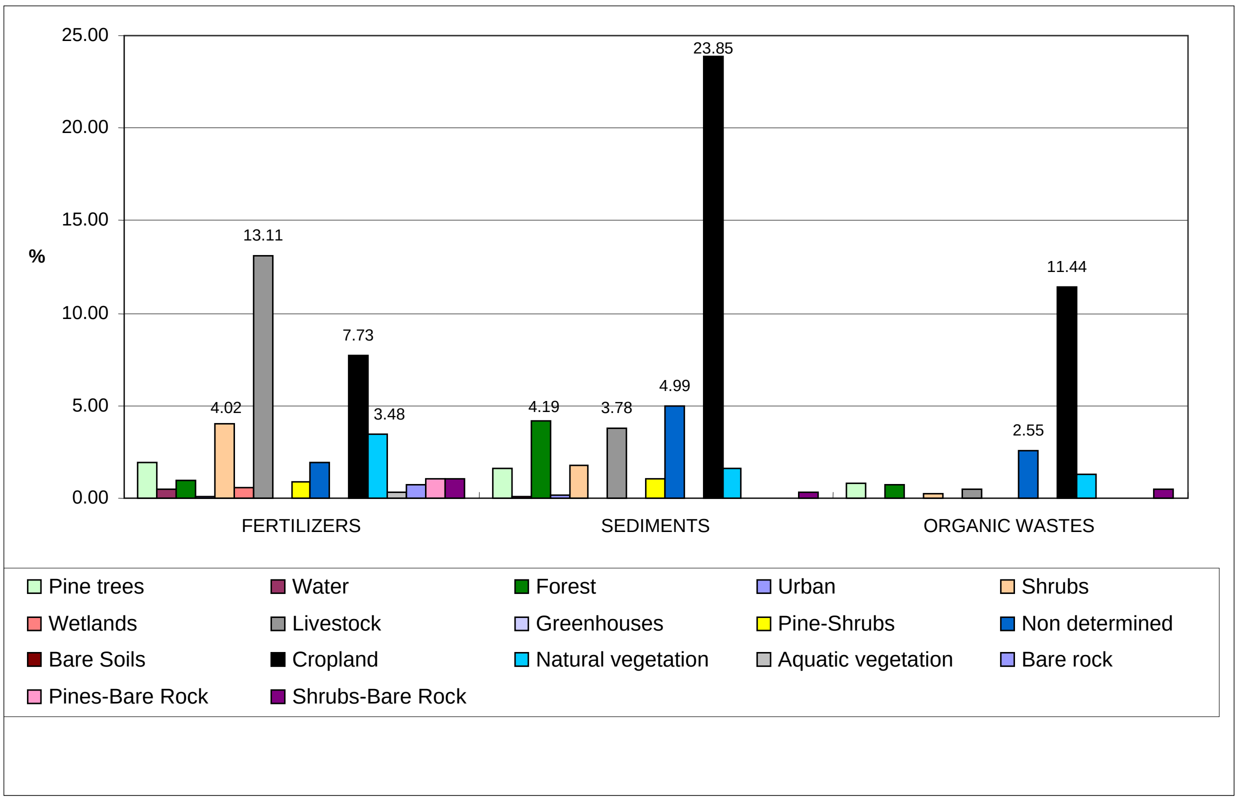

Figure 27. Percentage of existing land uses on areas that are considered specifically as predominant sources of pollutant based on the use of stable isotopes.

Progress towards achieving output level outcome

- *Principles, concepts and methods inform technology and system development*

The objective of Output 1 is to develop methods and principles that underlie efforts to improve the health and fertility of soils. Such international public goods (IPGs) foster innovative soil management strategies and inform the technology development and adaptation processes conducted in Output 2. This output has two aspects: one is the improved understanding of the process informing the development of technologies and systems that improve the fertility of soils and soil health; and the second aspect concerns the contribution of the improved soil health and fertility to resilient production systems and sustainable agriculture.

Development of principles, concepts and methods involve continuous and detailed review of the literature to identify key research questions and research gaps, that are translated into laboratory, greenhouse and field experiments with increasing on-farm research activities. Robust techniques for analyzing heterogeneity of socio-economic and biophysical factors influencing soil fertility management and soil fertility outcomes have now been developed, tested, and applied in a diversity of environments and socio-cultural settings. Research has focused more and more on land management practices, like agroforestry, reduced-till and crop-livestock systems, and their possible impacts of soil fertility and the natural resource base. Impacts evaluated range from changes in populations of soil microorganisms, changes in soil organic matter, soil P pools and water infiltration, changes in nutrient use efficiency in response to organic and inorganic nutrient sources, to changes in nutrient and resource flows at the farm and village scales in Africa and Latin America. Greater insights have been gained by the careful consideration of the agro-ecological and socio-economic contexts where these land management practices are tested thus increasing our capacity to develop relevant technologies and methods for sustainable land management. The studies into resource allocation on farm and soil fertility gradients within and across farms, are an example. Several studies on fallow management (looking at options for ISFM/nutrient management strategies and the effect on crop performance, fallow management for recovery of soil fertility status, effect of manure application on soil organic matter fractions and soil health status and the like) have greatly contributed to our insight on how such technologies can be applied to improve the natural resource base within the context of the farming system. Studies into historical land management practices help to identify possible new technologies and practices (e.g. work on bio-char). In many ways these studies, apart from developing principles and concepts, are at the same time a test of technologies developed, like the high fertility trenches technology for hillsides. Investigation of the applicability of conservation agriculture in different systems has confirmed opportunities for introduction of no-till systems on the Colombian savanna Oxisols. Though the basic principles of conservation agriculture are known, their short and long-term effects on the natural resource base, and the applicability to different management systems (in Africa and elsewhere) need to be further investigated.

In relation to below-ground biodiversity (BGBD) and the role of soil organisms in maintaining soil fertility and sustaining agricultural production, the inventory of BGBD in many different benchmark areas has contributed significantly to our insights of what is actually there (including new species discovered) and the impact of changing land use and on the abundance and diversity of soil organisms belonging to various functional groups. The BGBD project has successfully concluded its first phase and a publication summarizing common standard methodologies for soil biodiversity inventory has been completed after validation across carefully selected benchmark sites in Brazil, India, Indonesia, Ivory Coast, Kenya, Mexico and Uganda. Continuing studies into the mechanisms by which soil organisms interact with the other biological components helps us to understand the role and function of these particular soil organisms (e.g. suppression of soil borne pest and diseases), as indeed a basis for developing biological technologies. Investigation of awareness and knowledge of farmers on soil organisms and their beneficial or harmful effects, help to develop management options, of which options for managing earthworm populations may be the most advanced.

Identification of appropriate indicators of soil quality has remained an elusive exercise because it has been complicated by the need to simultaneously address the multiple dimensions of soil function (i.e. ecosystem services), the many physical, chemical and biological factors controlling biogeochemical processes as well as their variability in space and over time. Intensive work with a large number of farmers groups in various locations in Africa and Central America has documented a diversity of rich, context-specific knowledge, priorities, and constraints of smallholders relating to soil fertility management. An innovative community-based learning strategy has successfully stimulated the growth of a "dynamic expertise" that combines local and outsiders' soil fertility management knowledge, and may be used elsewhere as a framework for interaction between farmers, scientists and extension workers with a view towards scaling this expertise up and out using local networks and institutions. Approaches and methodologies to integrate local and scientific indicators of soil quality aim to incorporate local demands and perceptions of soil management constraints as an essential input to relevant research for development activities as well as to empower local communities to develop soil quality monitoring and decision-making systems for better management of the soil resource. Farmers need early warning signals and monitoring tools to help them assess the status of their soil, since by the time degradation is visible and land productivity reduction evident, it is either too late or too costly to reverse it. Furthermore, the costs of preventing reductions in land productivity are often several times less than costs of remedial actions. Conventional approaches to land quality assessment have looked at the physical and/or chemical characteristics of the soil. More recent approaches, however, have included integrative measures like Near Infrared Reflectance Spectrometry-NIRS and biological measures to assess soil quality. Biological indicators have the potential to provide early warning because they can capture subtle changes in land quality as a result of their integrative nature that simultaneously reflects changes in physical, chemical and biological characteristics of the soil.

Progress towards achieving output level impact

- *Improved soil health and fertility contribute to resilient production systems and sustainable agriculture*

In Output 1, the physical, chemical and biological dimensions of soil research have been addressed. Nevertheless it is only in few cases when all dimensions have been studied in the same place and the same time in conjunction with labour and market constraints as proposed by the ISFM paradigm. Soil fertility decline is not a simple problem as it interacts pervasively over time with a wide range of other biological and socio-economic constraints to sustainable agroecosystem management. It is not just a problem of nutrient deficiency but also of inappropriate germplasm and cropping system design, of interactions with pests and diseases, of the linkage between poverty and land degradation, of often perverse national and global policies with respect to incentives, and of institutional failures. Tackling soil fertility issues thus requires a long-term perspective and holistic approach.

As indicated above much of the work on principles, concepts and methods to inform technology and system development does consider the contribution to resilient production systems and sustainable agriculture as well. To a certain extent these are implicit in the studies undertaken. The ex-ante studies that have been undertaken to evaluate the viability of proposed technologies address these concerns more explicitly. Monitoring and evaluation and impact studies are increasingly becoming an integral part of our research projects. Attention will be devoted to impact assessment, with a participatory nature, of the technologies introduced. For example, the work to identify and validate indicators of soil quality, including biological quality, using replicable methodology under smallholder conditions to support farmers' experimentation with soil fertility management options will feed directly into the impact assessment studies.

Output 2

Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical and socioeconomic processes

Output 2: Economically viable and environmentally sound soil, water, and nutrient management practices developed and tested by applying and integrating knowledge of biophysical and socioeconomic processes

Rationale

Process level information needs to be translated into sustainable soil fertility and land management practices, adapted to the environment in which these practices will be implemented. These environments are characterized by biophysical and socioeconomic traits and those can vary at different scales, from the household (e.g., different access to resources) to the watershed (e.g., different inherent soil quality across landscapes) to the region (e.g., different policy frameworks related to natural resource management). Integration of these factors in the development of sustainable soil fertility and land management practices and understanding on how these factors influence the final outlook and components (e.g., varieties, use of inputs) of these practices is a crucial strategic research issue addressed in this output.

Practices addressed in this output are touching upon various aspects of soil fertility and land management and address the management of these natural resources in the broadest sense, far beyond agricultural production per se. Such aspects include the management of nutrient cycles, belowground biodiversity, ecosystem services, and erosion control. Certain practices are targeting one of these aspects while others are rather integrating more aspects. In terms of improved nutrient cycling, efforts are made to integrate the supply and the demand side for nutrients, and to enhance the use efficiency of organic and mineral inputs. Traditionally, soil fertility management has addressed the supply side of nutrients through concepts such as synchrony, but it is equally important to include the appropriate germplasm that will drive the demand for those nutrients, in soil fertility management strategies.

Efficient use of inputs can be achieved through integration of mineral and organic inputs and targeting soil fertility niches at the farm and landscape scale. Translating strategic information on belowground biodiversity in management practices is expected to happen through management of specific biological pools through cropping system diversification or inoculation or through management of the physical conditions of the soil by integrating conservation agricultural principles. Soil-based ecosystem services are very much related to the quality/quantity of the soil organic matter pool and the regulation of greenhouse gas production and sequestration. Consequently, management of organic resources is paramount to implementing soil fertility and land management practices enhancing ecosystem services. Finally, diversification of contour structures and building up of an arable layer of soil is expected to drive the generation of practices restricting erosion and soil physical degradation.

While the above activities are focusing on the technical dimensions of the technology development and evaluation phase, specific activities addressing the socio-economic and policy constraints to the adoption of these options are simultaneously covered. Finally, Output 2 is expected to deliver enhanced farmer capacity to translate best principles for soil and land management into practices that are appropriate to their environment and decision aids, condensing that knowledge, for dissemination beyond the sites where this knowledge has been generated.

Milestones 2005

No milestones listed in CIAT Medium-Term Plan of 2005-2007

Highlights

- In trials in Western Kenya, aiming at determining limiting nutrients and site-specific responses to applied nutrients for different fields within a farm (soil fertility gradients), clear differences in above two attributes were found between different fields within a farm. This indicates that there is a clear scope for field-specific fertilizer recommendations, provided these are based on local soil knowledge and diagnosis.
- In Western Kenya, the 'push-pull system' was observed to substantially reduce both *Striga* germination and stemborer damage. While herbicide-resistant maize was observed to seriously reduce Striga emergence, resulting in significant response to fertilizer application, maize did not respond to application of fertilizer in the maize mono-crop systems with maize hybrid WH403. In the push-pull systems, application of fertilizer also led to higher Striga emergence but this did not affect the responsiveness of the maize to applied fertilizer.
- In Central Kenya, inoculation with AMF showed considerable potential to enhance the early growth of tissue-culture bananas. Initial observations have also shown significant enhancements in banana growth after application of specific combinations of nutrients as fertilizer.
- Showed that building an arable layer using subsoil tillage and lime + nutrient applications could improve yields of maize by 2 to 3-fold compared with conventional systems of crop production on acid infertile soils of the Llanos of Colombia.
- Preliminary results from the Water and Food Challenge Program funded project on Quesungual system indicated that soil losses under Quesungual Slash Mulch Agroforestry System (QSMAS) of different ages (2, 5 and >10 years) were less than 2 Mg ha^{-1} in 14 weeks in comparison to the 30 t/ha soil losses observed in the slash and burn treatments.

Output target 2006

- ***Decision support framework for ISFM developed, tested with and made available to stakeholders in at least two benchmark countries in Africa***

Published work

D. Lesueur[1] and R. Duponnois[2] (2005) Relations between rhizobial nodulation and root colonization of *Acacia crassicarpa* provenances by an arbuscular mycorrhizal fungus, *Glomus intraradices* Schenk and Smith or an ectomycorrhizal fungus, *Pisolithus tinctorius* Coker & Couch. Annals of Forest Sciences 62: 467-474.

[1]TSBF-CIAT; [2]IRD, Burkina Faso

Abstract. The present study was initiated to (i) determine the ability of an ectomycorrhizal and an arbuscular mycorrhizal symbiont to colonize three provenances of *Acacia crassicarpa* root systems, (ii) to examine plant growth response to the mycorrhizal inoculation and (iii) to measure their influence on the rhizobial symbiosis with a *Bradyrhizobium* isolate. This study has been performed with 2 fungal symbionts: *Glomus intraradices*, an Arbuscular Mycorrhizal fungus, and an ectomycorrhizal fungus *Pisolithus tinctorius* strain GEMAS. Two experiments have been performed during two different climatic periods, hot season (30°C day, 20°C night, June to October) for ectomycorrhizal inoculation and cold season (25°C day, 15°C night, November to March) for endomycorrhizal inoculation. Moreover, *Bradyrhizobium* sp. strain Aus13C has been co-inoculated with each of these fungal symbionts. The results showed that ectomycorrhizal and AM fungal symbiosis clearly benefit to the growth of *A. crassicarpa* provenances and these fungal symbioses greatly improve the rhizobial nodulation process. However, some differences of growth were observed between the provenances tested and our results showed that both Papua New Guinea provenances produced more important total biomass than the provenance from Madagascar in both experiments However, no significant differences were observed in terms of nodulation and mycorrhization. Further research must be undertaken to identify the convenient ecological characteristics in which each kind of mycorrhizal symbiosis exerts the best effect on plant growth and nodulation formation and to identify in such environmental conditions the better rhizobial / mycorrhizal symbiosis combination.

A, Sarr[1], B. Diop[2], R. Peltier[3], M. Neyra[4] and D. Lesueur[5] (2005) Effect of rhizobial inoculation methods and host plant provenances on nodulation and growth of *Acacia senegal* and *Acacia nilotica*. New Forests 29: 75-87.

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Abstract. The purpose of this work was to determine the most efficient methods of inoculation to significantly improve nodulation and growth of *Acacia senegal* and *Acacia nilotica*, grown under greenhouse conditions. Our results showed that inoculation using dissolved alginate beads containing rhizobia significantly improved the growth of both acacias species better than the growth of plants in others treatments. The experiments with *A. nilotica* was done in two unsterilised soils from different areas. Plants grown in soil from Bel Air were well-nodulated and showed better growth than plants grown in soil from Sangalkam. However, no difference between these soils was shown between the several methods of inoculation and their effect on the nodulation and growth of plants. An interaction between *A. senegal* and *A. nilotica* provenances and the effect of inoculation with rhizobia was also demonstrated. Bel Air provenance of *A. senegal*, Dahra and RIM provenances of *A. nilotica* grew best of several provenances tested. These results suggest that (1) it may be possible to improve growth and yield of *A. senegal* and *A. nilotica* by careful selection of each symbiotic partner ; and (2) nursery-grown seedlings of *A. senegal and A. nilotica* should be inoculated, just after sowing, with dissolved alginate beads containing a mixture of selected rhizobia.

Completed work

Strengthening the competitiveness of organic agriculture in Africa through linking farmers to service providers and exporters

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If international and domestic markets continue their projected growth rate, the increasing demand for organic commodities will raise numerous questions about agronomic, economic and social factors that act as barriers to the further development of organic agriculture. Therefore, the future expansion of organic exports not only depends on growing export markets overseas, but on pro-organic research that backs organic growers and traders to produce more of what is demanded from the marketplace. This paper reports on a novel approach of building partnerships between farmers, non-governmental organization, exporters and research to ensure that the increasing organic demand for existing and new export products from the tropics can be realized. Linking demand to the production of organic produce demands a sustained, collective capacity of farmers for generating site-adapted natural resource management strategies and social innovations focusing on improving livelihoods. The project is implemented in two pilot sites in western and central Uganda and central Mozambique. In each site a combination of action research supports farmers in establishing linkages with organic markets. This transition process from traditional to market-led organic production is based on many years experience of implementing the 'Enabling Rural Innovation' (ERI) approach developed by CIAT. Examples from these pilot sites in Uganda and Mozambique will show how this approach has enabled farmers to access new market information (e.g. prices, quantities, quality) and new research products (e.g. disease resistant germplasm, variety evaluation for export, investing in natural resources and soil fertility) on critical aspects of production and how they have used this new information to develop competitive and profitable export organic agroenterprises. Building farmers' capacities to learn about biological and ecological complexity using participatory approaches and involving farmers in experimentation is a critical success strategy for empowering farmers to be able to learn and to innovate. First experiences with the application of the ERI approach to the organic sector will be discussed. Results on farm-level productivity increases, cost-benefit analysis and profitability will be presented and discussed. Capacity building of farmers and their partners in research skills and development activities of individuals for group production and marketing will be presented.

Evaluation of resource management options for smallholder farms using an integrated modelling approach

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Farm-level analysis of trade-offs between soil fertility management alternatives is required to improve understanding of complex biophysical and socio-economic factors influencing decision making in smallholder farming systems and to identify opportunities for improving resource use efficiency. A farm characterization (IMPACT) tool linked to a generic (Household) optimization model was used to evaluate resource use on farms in contrasting wealth categories. The Household model optimized farm's gross margins taking into account productivity of crops and livestock, off-farm activities and food sufficiency. Alternatives for management of nutrient resource were simulated using APSIM for the crop production and RUMINANT for the livestock component. The output from the simulation models was fed into the Household model and evaluated within the biophysical and socio-economic boundaries of the farms. Analysis of the performance a poor farm by IMPACT produced a yearly negative net cash balance of US$ -7, mainly due to negative returns from the cropping system. The farmer relied on donated food and fertilizers. The cash balance was negative, even though she also sold labour to generate income. The net income balance on the poor farm would be increased to US$81 and N balance from 7 kg ha^{-1} to 10 kg ha^{-1} by expanding the area allocated to groundnut from the current 5% to 31%. This would, however, generate a huge demand in labour (46-man days more) and reduce the P balance from 0 to -1 kg ha^{-1}. Maize would be managed more efficiently on the poor farm by cultivating a smaller, well-managed area. A wealthy farm under a maize-dominated cropping system had a net cash balance of US$210, mainly from sell of crop products. Under current resource management, the net cash balance would be increased to US$290 by optimization of diet. The net cash balance for the wealthy farm would be further increased to US$448, and nutrient balances by 271 kg N ha^{-1} and 30 kg P ha^{-1} by expanding the management strategy where maize was grown with a combination of cattle manure and ammonium nitrate. To do this, the farmer would need to source more manure (or improve capture and the efficiency with which nutrients are cycled through manure) and invest in 110 man-days extra labour. Expansion of the area grown to groundnut without fertilizer inputs to a third of the farm reduced net cash balance by US$11 compared to the current crop allocation due to poor groundnut yield. This also increased labour demand by 155 man-days. Groundnut intensification on the wealthy farm would be more economical and labour-effective if a small area is grown with basal fertilizer. Despite reducing nutrient balances for the arable plots, feeding groundnut residues to lactating cows increased net cash balance for the current year through increased milk production.

Target area identification using a GIS approach for the introduction of legume cover crops for soil productivity improvement

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Amidst the economic backdrop of resource-poor farmers, combined research and extension efforts in Uganda have focused on developing and promoting potentially adaptable and economically acceptable agronomic technologies that suit farmers' situations. Practices like improved fallows with woody and herbaceous legumes (e.g. *Canavalia sp., Crotalaria sp., Mucuna sp., Lablab sp.,* and *Tephrosia sp.*) have been considered an appropriate approach to improving soil fertility management and an alternative to expensive inorganic fertilizers. Developing economic and easily adaptable organic matter technologies for resource-poor farmers is one aspect of the research problems but a bigger challenge is how to target such technologies to the most appropriate environmental niches at the farm level, based on the different socio-economic and biophysical conditions within an area. This constraint can be overcome if improved geo-referenced data management systems are used as decision support tools in data compilation and target prioritization to identify sites, through extrapolation from a limited empirical site characterization, to larger area specific target recommendations. Targeting of legume cover crops (LCC) to areas with actual and potential soil fertility management problems using a GIS approach was investigated. Using available datasets it was possible to define, identify, and map potential areas for targeting of LCC soil fertility improvement technologies by overlaying different maps of soil fertility status, cropping systems, population density and climate for the eastern region of Uganda. We show that GIS decision support systems can indeed provide targeted dissemination output to add decision making from a limited number of datasets. Shortcomings in the data are discussed, as are the practical applications of this approach in choosing appropriate legume species.

Output target 2006

➢ ***Cereal-legumes and livestock systems, with nutrient use efficiency as an entry point, tested and adapted to farmer circumstances in hillsides of Africa***

Completed work

Strengthening “Folk Ecology”: Community-based learning for integrated soil fertility management, western Kenya

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Farmers and researchers in western Kenya have used community based learning approaches to jointly developed a “dynamic expertise” of integrated soil fertility management (ISFM). This approach builds on farmers’ “folk ecology” and outsiders’ knowledge, taking action research on natural resource management beyond methods that are descriptive (ethnopedology) or curriculum-driven (farmer field schools). The paper presents insights from a project’s experience of applying the Strengthening “Folk Ecology” approach in western Kenya, with emphasis on the community-based learning process, collective and individual experimentation, the power dynamics of farmer research groups, and learning from the farmer-researcher interface. Farmer groups have been empowered by this approach but diversification into non-soil activities highlights the limitations of experimentation and the challenges of scaling up participatory action research.

Lessons learned (summarised)

1. Experiments must follow local logic
2. Expect different follow-up activities in different sites
3. Successful learning from ISFM empowers diverse group activities
4. Develop a shared language
5. Identify and work with diverse institutions and networks
6. Use formal and informal means to handle elites and disruptive personalities
7. Learn from dissent, silence, and “opting out”
8. Use diverse ways to understand and document “dynamic expertise”
9. Soil ecological knowledge is not universally held or understood

Challenges and opportunities

Knowledge-based models of intervention emphasise the building farmers’ understanding of science instead of simply following scientific recommendations (Dilts and Hate, 1996; Röling and van de Fliert, 1994). The SFE approach has also worked hard to have scientists and other outsiders understand and work with “folk ecology” to jointly develop a “dynamic expertise” for soil fertility management. Fundamental questions emerging from the lessons described above concern the further role of experimentation in building “dynamic expertise” and the limits and opportunities for scaling up participatory approaches such as SFE.

Experimentation

While “dialogue” has been central to the joint experimentation and learning within SFE, the project has kept an agnostic attitude towards whether “knowledge integration” as such is itself feasible or even useful. On the one hand, knowledge and opinions about soil fertility management clearly differed greatly within the communities. The heated debates between farmers about indicators, or the varying ways in which married women learn the ecology of their new homes, reflect that diversity. The benefits of bringing complementary knowledge together included identifying relationships and patterns, comparing observations across localities, and helping farmers and outsiders solve problems.

On the other hand, our findings show that locals and outsiders design and test experiments without major methodological differences. This suggests that while knowledge sets are compatible and complementary, we should not expect additional, conceptual "synergies" from farmers and researchers working together. Nevertheless, joint experimentation has created new sites of common experience and shared discovery. By linking new research questions to the emerging dynamic expertise, scientists are able to improve research by focussing on questions of immediate relevance to the farmer research groups (e.g. applying ISFM to under-studied home garden crops, improving composting technologies, providing wider range of multi-purpose legumes for farmer experiments, etc.).

For experimentation to remain important and useful to SFE, there must continue to be a wide range of prototype technologies for farmers to validate, adapt, and refine. For the moment, the emphasis has been on ISFM but the oldest groups (only four years old) are diversifying into activities where the researchers and other project partners have little expertise (e.g. credit, health, and nutrition, etc.). Even within the agronomic experimentation, there is an ever-increasing range of factors to manage (e.g. pest-management options, suitability of crop for climate and intercropping, product marketability, etc.). The capacity of a project team that had formed for one objective (studying the "folk ecology" of soil) is stretched as it moves to embrace ever more objectives, and further stretched if this is to cover yet more groups and sites. If ISFM is indeed destined for a supporting rather than a dominant role in farmer groups' activities, a soil-oriented research institute or project must be ready to accept new roles and responsibilities (and indeed phase itself out of the experimentation process when groups are ready).

Scaling up

The greatest criticism of SFE by scientists and other development practitioners has been that it is perceived as an "anthropological" (i.e. "time-consuming", "complicating rather than simplifying") approach. Farmer groups are indeed experimenting with and applying ISFM concepts, but on the scale of dozens of households, not hundreds or thousands. Impacts appear slowly, distributed unevenly across the social landscape.

One problem lies with the production of "dynamic expertise" itself. To be self-sustaining, this appears to need actors with different but complementary knowledge, new resources, and opportunities. Reducing the role of outsiders and outside knowledge as part of a phasing out process likely also diminishes the flow of new ideas, potentially stagnating the "dynamic expertise". Seeing the enthusiasm of farmer groups for "experimentation" in the project, participating researchers hoped that farmers would then start sharing the experimentation methods behind the new, "dynamic expertise". Instead, most farmer-to-farmer instruction downplayed the experimentation process, focussing instead on presenting "solutions" or "known concepts" that emerged from experimentation. While some of this mirrors the long-standing "transfer of technology" approach familiar to farmers, it is also true that farmers convinced that they have found "best bets" suited to their milieu wanted to share these directly with their friends and relatives and thereby spare them a lengthy experimentation process.

The scaling up of the "dynamic expertise" gained through SFE is not just about disseminating information or even the knowledge behind it, but also about institutionalising new power and confidence to challenge existing structures and assumptions. The potential of groups and social networks to disseminate dynamic expertise or the SFE approach is therefore fundamentally linked to inherent, complex, internal politics and not just the quality of the ideas or technologies. It has become fashionable to suggest that "more" or "better" quality participation can overcome such power structures. However, our experience has shown that groups survived, grew in number, and diversified only in response to the availability of new knowledge, resources, and contacts with outsiders. This finding further reinforces the conclusion that the institutionalisation of the SFE approach in local groups and project partners will take it in multiple directions, subject often to the availability of resources to support the latest activities within the groups' "dynamic expertise". This may appear humbling to soil scientists, but should be a healthy sign, evidence that ISFM can and will be only a subcomponent of improved livelihood strategies.

Nitrogen cycling efficiencies through livestock in African resource-poor mixed farming systems: A review

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Abstract. Success in long-term agricultural production in resource-poor farming systems relies on the efficiency with which nutrients are conserved and recycled. Each transfer of nutrients across the farming system provides a risk of inefficiency, and how much is lost at each step depends on the type of farming system, its management practices and site conditions. The aim of this review was to identify critical steps where efficiency of nitrogen (N) cycling through livestock in smallholder crop–livestock farming systems could be increased, with special emphasis on Africa. Farming systems were conceptualized in four sub-systems through which nutrient transfer takes place: (1) livestock: animals partition dietary intake into growth and milk production, faeces and urine; (2) manure collection and handling: housing and management determine what proportion of the animal excreta may be collected; (3) manure storage: manure can be composted with or without addition of plant materials and (4) soil and crop conversion: a proportion of the N in organic materials applied to soil becomes available, part of which is taken up by plants, of which a further proportion is partitioned into grain N. An exhaustive literature review showed that partial efficiencies have been much more commonly calculated for the first and last steps than for manure handling and storage. Partial N cycling efficiencies were calculated for every sub-system as the ratio of nutrient output to nutrient input. Estimates of partial N cycling efficiency (NCE) for each subsystem ranged from 46 to 121% (livestock), 6 to 99% (manure handling), 30 to 87% (manure storage) and 3 to 76% (soil and crop conversion). Overall N cycling efficiency is the product of the partial efficiencies at each of the steps through which N passes. Direct application of plant materials to soil results in more efficient cycling of N, with fewer losses than from materials fed to livestock. However, livestock provide many other benefits highly valued by farmers, and animal manures can contain large amounts of available N, which increases the immediate crop response. Manures also can contribute to increase (or at least maintain) the soil organic C pool but more quantitative information is needed to assess the actual benefits. Making most efficient use of animal manures depends critically on improving manure handling and storage, and on synchrony of mineralization with crop uptake. Measures to improve manure handling and storage are generally easier to design and implement than measures to improve crop recovery of N, and should receive much greater attention if overall system NCE is to be improved

Enhancing the productivity and sustainability of Integrated Crop-Livestock Systems in the dry savannahs of West Africa

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Traditional farming systems are breaking down as evidenced by shortened fallow periods and expansion of agriculture onto marginal lands. These changes result in lowered productivity and the emergence of unsustainable farming practices with potentially disastrous consequences for poor people, their food security and their environment. Although some technologies are available, they are not adopted by farmers due to high costs and unavailability of inputs. Alternative technologies involving cereals, grain legumes, ruminant livestock and improved agronomic practices in an integrated and holistic manner could be an appropriate response to ameliorating soil fertility, crop yields, feed quantity and quality for livestock. A multi-center, multi-disciplinary approach was implemented using farmer participatory research to understand and address the constraints faced by smallholder crop-livestock farmers in the dry savannas of West and Central Africa. The benefits of working together are at least additive, but

synergistic effects are also anticipated. A pilot project was implemented in Kano State, northern Nigeria in 1998 and in 1999 this was expanded to include another site in northern Nigeria as well as sites in Mali and Niger. This paper describes the implementation, evolution and progress of a new approach to improving crop-livestock farming in the dry savannahs whereby best bet packages involving elements of crop varieties, crop geometry, soil fertility, residue and livestock management are assessed on-farm using a holistic strategy including biophysical and socioeconomic monitoring

A critical analysis of challenges and opportunities for soil fertility restoration in Sudano- Sahelian West Africa

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Since the 1970s, research throughout West Africa showed that low soil organic matter and limited availability of plant nutrients, in particular phosphorus and nitrogen, are major bottlenecks to agricultural productivity, which is further hampered by substantial topsoil losses through wind and water erosion. A few widely recognized publications pointing to massive nutrient mining of the existing crop-livestock production systems triggered numerous studies on a wide array of management strategies and policies suited to improve soil fertility. Throughout West Africa, the application of crop residue mulch, animal manure, rockphosphates and soluble mineral fertilizers have been shown to enhance crop yields, whereby yield increases varied with the agro-ecological setting and the rates of amendments applied. In more humid areas of Western Africa, the intercropping of cereals with herbaceous or ligneous leguminous species, the installation of fodder banks for increased livestock and manure production, and composting of organic material also proved beneficial to crop production. However, there is evidence that the low adoption of improved management strategies and the lack of long-term investments in soil fertility can be ascribed to low product prices for agricultural commodities, immediate cash needs, risk aversion and labour shortage of small- scale farmers across the region. The wealth of knowledge gathered during several decades of on-station and on-farm experimentation calls for an integration of these data into a database to serve as input variables for models geared towards *ex-ante* assessment of the suitability of technologies and policies at the scale of farms, communities and regions. Several modelling approaches exist that can be exploited in this sense. Yet, they have to be improved in their ability to account for agro-ecological and socio-economic differences at various geographical scales and for residual effects of management options, thereby allowing scenario analysis and guiding further fundamental and participatory research, extension and political counselling.

Appropriate available technologies to replenish soil fertility in southern Africa

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In southern Africa, natural fallows which were traditionally used to replenish soil fertility are becoming increasingly rare. The nutrient reserves of the soils are being depleted because of insufficient fertilizer application. The consequent downward spiral of soil fertility has led to a corresponding decline in crop yields, food insecurity, food aid and environmental degradation. The central issue for improving agricultural productivity in southern Africa is how to build up and maintain soil fertility despite the low incomes of smallholder farmers and the increasing land and labour constraints they face. Under this review five main options: inorganic fertilizers, grain legumes animal manures and integrated nutrient management and agroforestry options are available and appropriate to smallholder farmers. Issues to be addressed in the use of inorganic fertilizers are reduction in the costs of fertilizers, increase their timely availability and increase in fertilizer use efficiency and profitability. Legumes can be used to diversify farm system productivity. Further, markets have to be developed for various legume products. Soil fertility on many farms has to be raised especially with P and lime application to support better legume growth and biological nitrogen fixation (BNF). Selecting and breeding legume crops for low soil fertility conditions is also imperative. Manure availability and quality are central issues in application of animal manures by smallholder farmers. Increasing efficiency of manure quality and quantity through proper handling and application methods should be pursued. Farmers will not have adequate amounts of either inorganic or organic inputs. Integrated nutrient management of soil fertility by combined application both inputs will increase use efficiency of inputs and reduce costs and increase profitability. Ways of improving availability of organic inputs on farms will be discussed. Issues such as quality of inputs, nutrient balancing, labour to collect and transport organic inputs and their management need to be optimized. These factors are challenges of adoption and scaling up of these options to millions of smallscale farmers. Factors which will facilitate adoption are, develop wide range of options with farmers, good germplasm delivery systems, sharing of knowledge and information and policy options to favour these practices.

Appropriate available technolologies to replenish soil fertility in Eastern and Central Africa

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Low inherent soil fertility in the highly weathered and leached soils largely accounts for low and unsustained crop yields in most African countries. But in particular, the major nutrients, N and P, are commonly deficient in these soils. This scenario of nutrient depletion is reflected in food deficits and hence the food aid received continuously, particularly in sub-Saharan Africa. Undoubtedly, substantial efforts have been made in the continent to replenish the fertility of degraded soils in attempts to raise crop yields, towards self-sufficiency and export. Such efforts consist of applications of both organic and inorganic nutrient resources to improve the nutrient status of soils. Overall, positive crop responses to these materials have been obtained. Thus in the East African region, maize (staple) yields have been raised from below 0.5 Mg ha^{-1} without nutrient inputs, to 3-5 Mg ha^{-1} from various nutrient amendments at-on-farm level. In this paper, we highlight the impacts of using materials of different characteristics (qualities) in relation to improved crop yields but specifically the phosphate rocks that are widely distributed in Africa. Due to low purchasing power of the smallhold farmers, who constitute over 80% of farming communities, we suggest the production of low cost packages, such as the "PREP-PAC", which target the correction of specific soil fertility problems. PREP-PAC ameliorates the fertility of the worst soil fertility patches common on smallhold farmlands. Economic based information is also given related to the use of various soil fertility management technologies. Above all, the paper underscores the need for side-by-side comparisons of options for soil fertility replenishment. This approach empowers the farmer to observe, rate and choose the promising technologies but pinpointing the economic factors. This appears to be one way forward towards the technology adoption process.

Within-farm soil fertility gradients affect response of maize to fertilizer application in western Kenya

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Different fields within a farm have been observed to have different soil fertility status and this may affect the response of a maize crop to applied N, P, and K fertilizer. A limiting nutrient trial was carried out at six farms each, in three districts of Western Kenya. In each of the farms, the following treatments were laid out in three fields with different soil fertility status at different distances from the homestead (close, mid-distance, remote fields): no inputs, application of NPK, NP, NK, or PK fertilizer (urea, triple super phosphate, KCl) to maize. Total soil N decreased at all sites with distance to the homestead (from 1.30 to 1.06 g kg^{-1}), as did Olsen-P (from 10.5 to 2.3 mg kg^{-1}). Grain yields in the no-input control plots reflected this decrease in soil fertility status with distance to the homestead (from 2.59 to 1.59 Mg ha^{-1}). In the NPK treatments, however, this difference between field types disappeared (from 3.43 to 3.98 Mg ha^{-1}), indicating that N and P are the major limiting nutrients in the target areas. Response to applied N was related to the soil total N content in Aludeka and Shinyalu, but not in Emuhaya, probably related to the high use of partially decomposed organic inputs with limited N availability. Consequently, response to

applied N decreased with distance to the homestead in Aludeka (from 0.95 kg kg^{-1} relative yield to 0.55 kg kg^{-1}) and Shinyalu (from 0.76 kg kg^{-1} to 0.47 kg kg^{-1}), but not in Emuhaia (from 0.75 kg kg^{-1} to 0.68 kg kg^{-1}). Response to applied P was related to the soil Olsen-P content at all sites. While for farms with a relatively high Olsen-P gradient, response to applied P decreased with distance to the homestead (from 0.99 kg kg^{-1} to 0.68 kg kg^{-1}), large variability in Olsen-P gradients across field types among farms within a specific site often masked clear differences in response to P between field types for a specific site. Clear scope for field-specific fertilizer recommendations exists, provided these are based on local soil knowledge and diagnosis. Scenario analysis, using farm-scale modelling tools, could assist in determining optimum allocation strategies of scarcely available fertilizer for maximum fertilizer use efficiency.

Work in progress

Value of farmer-demonstration trials as a community-based knowledge transfer tool: Vegetable fertilization trials

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Food insecurity is a serious challenge facing the social and economic development of Kenya. Soil fertility improvement via fertilizer amendments is a common method used by governments, and research and development organizations to combat food insecurity at the farm level. The objective of this paper is to assess the effectiveness of farmer-demonstration trials (FDTs) as an educational tool for relaying soil fertility technologies, new materials and methodologies, to small-landholder farmers. This will be done by assessing their scientific value. Results showed that the yield and nutrient response of four indigenous vegetables to four treatments were inconsistent. No single treatment increased either particular nutrients or yields in any vegetables. The use of *Tithonia diversifolia* is perhaps the most promising; however, more scientifically rigourous methodologies must first be used, with the aid of community farming groups, before any confident statements can be made on response. The positive response of farmers, in their participation and adoption of technologies showed that FDTs are an effective knowledge transfer tool. Development organizations using FDTs need to ensure that scientific methodologies in experiment design are followed as closely as possible.

Local Logic and Species Selection

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New legume species or any other technology however ‘promising’ should never be recommended for wide-scale application by farmers until it has been rigorously evaluated, especially through participatory processes in the field under realistic conditions. Species screening was undertaken as a tool for interactive learning between farmers and researchers, which stimulated rigorous evaluation of selected new varieties. The overall objective of this exercise was to understand farmers’ and other individuals’ criteria for accepting or rejecting varieties of legumes. This objective was achieved through i) tools of dialogue ii) partnerships with local farmer field schools (FFS) and farmer research groups (RGs) for a period of two years to manage screening plots and iii) systematic visits to screening plots for participatory evaluations. Evaluations were carried out i) by farmers filling in collectively designed ‘plot performance forms’ ii) through focus group discussions iii) through in-depth interviews and iv) by holding soybean utilisation field days. Results showed that the most important underlying criteria for preference of new species were based on sustainability. Sustainability was determined by key aspects of local logic: tolerance to low rainfall, high maturity rate, higher harvest and resistance to pests and diseases. Preferences derived from differentiation between species on the basis of cost of production, seed longevity and price differences on local produce markets were yet to be discerned well by farmers. These three factors take longer to be appreciated.

‘Opting out’: Explaining rejection of soil fertility research and knowledge among many smallholder farmers of western Kenya

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By embracing participatory research processes and scaling up of integrated soil fertility management (ISFM) and knowledge, many institutions expected significant increase in agricultural production. This has not been the case. This paper therefore is a case study of the rejection of participatory ISFM research and knowledge among selected smallholder farmers of western Kenya. C*ritical case sampling* was used to select cases of ‘opting out’ of the research process. These cases were identified as being particularly notable. Results showed that farmers’ decisions over participation in research and scaling up activities were shaped by factors such as facilitation skills, long-term vs. short-term gains, personality and the local ‘politics of research’, contradictory policies or practices of research institutions and the nature of ISFM technologies researched or disseminated. This paper therefore suggests that researcher-farmer and farmer-farmer partnerships are necessary for longer-term goals. Such partnerships can be achieved if policies and practices of collaborating institutions are harmonised and participatory research objectively guided and reviewed against longer-term objectives.

Effects of cotton-cowpea intercropping on cowpea N_2 fixation capacity, nitrogen balance and yield of a subsequent maize crop under Zimbabwean rain-fed conditions

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Intercropping cotton and cowpea is one of the ways to improve food security and soil fertility while maintaining cash income of the rural poor. A study was carried out to find out the effect of cotton-cowpea intercropping on cowpea N_2-fixation capacity, nitrogen balance and yield of a subsequent maize crop. The treatments for the first season were; sole cotton, sole cowpea, 1 row of cotton alternating with 1 row of cowpea (1:1) and 2 rows of cotton alternating with 1 row of cowpea (2:1) and these intercrops were planted at the same time (simultaneously). The second season treatments were maize sown to the plots that had intercrops with no N fertilizer added and these were compared to three levels of fertilizer application i.e. 0, 30 and 60 kg N ha^{-1}. Results showed that cowpea suppresses cotton yields but the reduction in yield was compensated for by cowpea grain yield of and also the residual fertility from cowpea residues. Intercropping cotton and cowpea increased the biological productivity (as shown by land equivalence ratios which were greater than 1.0 for the intercrop treatments) of the system, increased food security and improved soil quality. Cowpea grain yield was as follows, sole cowpea (1.6 Mg ha^{-1}), 1:1 intercrop (1.1 Mg ha^{-1}), and 2:1 intercrop (0.7 Mg ha^{-1}). Cotton lint yield were, sole cotton (2.5 Mg ha^{-1}), 1:1 intercrop (0.9 Mg ha^{-1}) and 2:1 intercrop (1.5 Mg ha^{-1}). The intercrops were productive as compared to the sole crops with an average land equivalence ratio (LER) of 1.3 for both dry matter and grain yield. There was an increase in N_2-fixation by cowpea in intercrops as compared to sole crops though the amount fixed was lower due to reduced plant population. Sole cowpea had N_2-fixation of 73%, 1:1 intercrop had 85% and 2:1 intercrop had 77% while the total amount derived from N_2-fixation was, sole cowpea (104 kg ha^{-1}), 1:1 intercrop (96 kg ha^{-1}) and 2:1 intercrop (51 kg ha^{-1}) . Sole cowpea and the intercrops all showed positive N balances of 42.5 kg ha^{-1} for sole cowpea, 60.0 kg ha^{-1} for 1:1 intercrop and 25.7 kg ha^{-1} for 2:1 intercrop. Cowpea fixed N transferred to the companion cotton crop was very low with 1:1 intercrop recording 3.5 kg N ha^{-1} and 2:1 intercrop 0.5 kg N ha^{-1}. Maize grain yield was as follows, after sole cotton (1.1 Mg ha^{-1}), sole cowpea (3.0 Mg ha^{-1}), 1:1 intercrops (2.8 Mg ha^{-1}) and 2:1 intercrops (2.5 Mg ha^{-1}). The previous crop residue were beneficial especially from intercrops and sole cowpea than from sole cotton as shown by reduced yields following sole cotton. The LER, yield, %N fixation and, positive N balance and residual fertility shows that cotton-cowpea intercropping is a potentially productive and ecologically sound system that can easily fit into the current smallholder farming systems.

Creating niches for integration of green manures and risk management through growing maize cultivar mixtures in southern Ethiopian Highlands

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Maize yield fluctuation in small scale farms of East Africa is associated mainly to intermittent drought, soil fertility decline and choice of intercrops. On-farm experiments were conducted between 2000 and 2004 in Areka, Southern Ethiopia to evaluate the effect of maize mixtures or pure stands on maize grain yield and the biomass production of vetch (*Vicia dasycarpa*) when grown as an intercrop under fertile or non-fertile farm plots. We used mid-late maturing, A511 (145 days, 2.45m tall) and early maturing, ACV6 (120 days and 2.04m tall) maize varieties and a local vetch . Under sole cropping, the grain yield of mixtures was significantly higher (by 1.5 tha^{-1}) ($P<0.05$) than early variety, cv ACV6, but lower than the late maturing variety, cv A511, across years. Similarly, the grain yield of mixtures was significantly higher than sole cv ACV6 but lower than A511 in fertile plots while ACV6 out yielded both late maturing variety and the mixtures in less fertile plots. Intercropping with vetch did not affect the yield of mixtures while it caused a significant yield decline in A511, by about 35% ($p<0.05$), particularly in years with intermittent drought. On the other hand, vetch biomass was significantly reduced under intercropping with maize, by 94% in A511 but 66% in mixtures. Vetch was more sensitive to low soil fertility than maize. Farmers' evaluation indicated that cultivar mixtures could intensify their systems by leaving space for intercropping, shortening hunger period, minimizing risk of complete crop failure and as a stake. Maize mixtures could be functional niches to integrate green manures and facilitate adoption for soil fertility improvement which other wise were not accepted by farmers for scarifying one season to grow them as fallows.

Increasing efficiency of use of green manure legumes through minimizing trade-offs between soil fertility management and livestock feed

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There is a broad understanding about the importance of legumes as soil fertility restorers, quality livestock feed, pest and disease cycle breakers, improved human nutrition and many other uses. However, integration of legumes in various systems of East African Highlands remained to be elusive as discussed earlier (Amede and Kirkby, 2004; Amede, 2004). In our earlier attempts we showed that various food, feed and green manure legumes have various farm and household niches, but not all options are fitting to all systems. Despite a significant increase in crop yield as an after effect of legume cover crops less than 10% of the farmers were willing to integrate them in to their system due to associated opportunity costs of land, labour and other inputs. Even those farmers who integrated legumes were searching for alternative niches in the farm to minimize competition for production resources with food crops. Some farmers started to grow them at farm borders to use for biomass transfer while others were growing them on low fertile farm corners but remove the above ground biomass for feed. This activity, which started in 2004 in collaboration with the African Soils Network, Afnet, was set to quantify the trade-offs between soil fertility, livestock feed and other uses in Areka, southern Ethiopia. The system is characterized by intensive cropping with a clear soil fertility gradient from the homestead to the outfield. The soils are predominantly nitisols, with high P fixation, Al accumulation and low pH (for details Amede et al., 2001). This year's experiment evaluated the biomass productivity of four various green manure legumes namely Lablab (*Lablab purpureus*), Soy bean (*Glycine max*), Crotalaria (*Crotalaria ochroleuca*) and Vetch (*Vicia dasycarpa*) in the first season. In the second season, these legumes were chopped at late flowering stage and incorporated to the soil in three different ways. In the first case, all biomass was chopped and incorporated in to the same plot where the legume crop was grown, in the second treatment the above ground biomass was removed and only the below ground biomass (roots) are left and the above ground biomass is used as a source of biomass transfer and in the third case the above ground legume biomass, which is produced in a plot was applied in another nearby plot. Three weeks after incorporation a wheat crop was planted in the same season on these various legume treatments, using 100 kg ha^{-1} TSP across treatments. Additional research plots of Urea (50 kg ha^{-1}) and TSP/Urea (150 and 50 kg ha^{-1}) and check (without application of organic or chemical fertilizers) were included for comparison.

Table 16.. After effects of various legumes, when applied as whole biomass or roots only or above ground biomass only, on wheat yield in Areka, Southern Ethiopia, 2005.

Legume source	Legume biomass weight (Mg ha^{-1})	Wheat grain yield (Mg ha^{-1})	SE	Wheat biomass Yield (Mg ha^{-1})	SE	Plant height (cm)	SE
Lablab whole biomass	21.00	7.	0.31	11.43	2.23	88.88	3.72
Lablab above ground	18.25	5.72	0.83	5.75	0.86	71.06	2.85
Lablab roots only	ND	6.23	0.28	6.58	0.82	79.38	2.32
Soya whole biomass	13.38	5.81	0.26	7.67	0.58	80.38	1.67
Soya above ground	14.13	6.07	0.85	6.33	0.24	77.25	3.39
Soya roots only	ND	5.68	0.25	6.08	0.75	80.63	2.13
Crotalaria whole biomass	-	4.25	0.19	5.83	1.97	78.31	3.94
Crotalaria above ground	-	3.03	0.39	3.00	0.14	65.25	1.52
Crotalaria roots only	ND	5.82	0.28	5.33	1.03	73.69	1.83
Vetch whole biomass	4.75	5.82	0.37	7.67	2.83	74.38	7.38
Vetch above ground	5.00	3.56	0.35	4.25	1.31	67.31	4.10
Vetch roots only	ND	4.42	0.48	5.83	1.88	74.63	7.18
Urea		5.54	0.40	5.75	1.01	77.38	3.32
TSP and Urea		7.38	0.47	7.17	1.29	76.31	5.62
Check		3.45	0.22	3.17	0.50	66.56	1.79

Similar to the findings in 2004, wheat yield was affected by the type of the preceding legume, and wheat yield varied with whether all the biomass or only the above ground biomass was incorporated into the soil. The highest grain and biomass yield across treatments was obtained from lablab followed by chemical fertilizers. Wheat yield was higher in the legume fields than the chemical fertilizers. It was also higher when the total biomass was incorporated to the soil than when only the roots or the above ground biomass was incorporated. Grain yield of wheat was also higher when wheat was grown in the legume fields where roots are left than in fields where the above ground biomass was applied as a biomass transfer (Table 16). The population of wheat was lower in fields where total biomass was incorporated than in fields where only roots or only shoots were applied, implying that seed emergency could be reduced under whole biomass incorporation, especially when it is planted after a short period of decomposition. The most important finding of this work was that farmers could grow legumes as a short term fallow, cut the above ground biomass for the animal feed and yet they could get between 30 and 90% yield advantage over the control. In situation where they incorporate the whole biomass in the same plot they yield advantage could be more than 100%, as it was observed in lablab (Table 16). Soil analysis is going to be conducted in early 2005 to finalize the work.

Enhancing the productivity of degraded outfields through increasing farmers capacity and integration of improved practices

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There is a national consensus in Ethiopia among policy makers, environmentalists and development institution that soil erosion has been one of the most chronic problems of the agricultural system, and attracted attention of donors and development institutions to invest on terracing since the 1980s. Besides soil erosion, hundreds of years old exploitive land use aggravated by increased human and livestock population lead to the extraction of natural capital, mainly through farming of sloping lands and overexploitation of slowly renewable resources . The effect is reflected through disruption of biological processes such as loss of biological diversity and vegetative cover, soil loss, nutrient imbalance, decline in soil organic matter, decrease of water retention capacity. The soils in Southern Ethiopian Highlands, Areka, are characterized as Nitosols, highly weathered, and subject to intensive cultivation with out external inputs. Various attempts to integrate land management technologies by a wide range of governmental and non-governmental institutions continues to prove unsuccessful, and soil fertility decline in small scale farms remained to be an intransigent problem. The rural poor in the region are often trapped in this vicious poverty cycle between poor access to resources (poverty), land degradation, and lack of relevant knowledge and/or appropriate technologies to generate adequate income and opportunities to overcome land degradation. As crop/livestock production is the major source of household income, decline in soil fertility, through nutrient depletion and poor soil water holding capacity affected the on-farm income, labour productivity and crop and livestock yield significantly. There is an increasing human population in this region in recent years, which have significantly contributed to land fragmentation and reduced farm size to less than 0.5 ha per family of 7 . Moreover, there is a huge variability in soil fertility status within a farm, whereby the homestead fields are more fertile than the far away outfields due to deliberate allocation of resources in favour of more intensified homestead fields . As a result the productivity of the outfields has been declining over years and is currently in a situation whereby most crops either fail to grow or produce significantly low yield.

An integrated research approach was sought whereby a combination of improved interventions and farmers' innovations has been employed to address land degradation at landscape and farm levels. The major objective of the research were a) to enhance the capacity of farmers to identify the degradation hotspots within their farm and beyond, 2) to identify low cost and easy to use technologies to address soil fertility decline and 3) to evaluate the effects of these interventions on crop yield and soil fertility parameters in the short term.

The research was done in Gununo, Areka district, Southern Ethiopia, which is one of the AHI benchmark sites. The farming system could be characterized by multiple cropping system growing diverse annual and perennial crops including enset and coffee sweet potato, taro, maize, wheat and many others. It is one of the highly populated districts in the country (>400 people km-^{2}), with average land holdings of less than 0.5 ha. At between 1880 and 1960 meters above sea level, this area has mean annual rainfall of about 1300 mm, and an average temperature of 19.5 ^{o}C. Rainfall is bimodal, with a short rainy season (belg) from March to June and the main rainy season extends from July to October, with July August receiving the highest rainfall. The dominant soils in the study area are Eutric Nitisols, very deep (>130 m), P-fixing, acidic in nature, and are characterized by higher concentration of nutrients and organic matter within the top few centimetres of the soil horizon. Following a participatory landscape analysis, fifteen representative farms with clear soil fertility gradients, and where soil fertility decline particularly in the outfield is apparent, were selected. The farmers, in consultation with their family members, identified the most unproductive crop field of their respective systems. We have then conducted a questioner to understand the root causes for soil fertility decline and the land use history of the respective farm units. We have also bookmarked 150 m^2 land area of a research plot in each farm corner to target innovations and improve the productivity of the farm through participatory research and innovation. Vetch was under sown under the potato crop two weeks after planting potato to minimize investments of land and labour and increase biomass production. There were three treatments namely wheat after vetch biomass, wheat after potato biomass and wheat control. The on-farm experiments were conducted by farmers in close consultation with researchers. Each farm is considered as a replicate. 30 kg ha-1 DAP was applied across all research plots. Vetch was under sown under the potato crop two weeks after planting potato to minimize investments of land and labour and increase biomass production.

The survey have indicated that decline in land productivity of the outfields is a consequence of multiple natural and human factors (data not presented), firstly due to a continual removal of crop residues from the out field to the homestead field as a mulch, to the stall as feed and to the house as a means of cooking fuel. Secondly, it receives the lowest amount of manure and household refusal because of distance effects and the deliberate favouritism to the homestead infield where the most important security crops, high value crops and planting materials are grown and propagated. Thirdly it is exposed to soil erosion because of limited physical and biological conservation measure in the far away fields. As presented in Table 17 there is a trend of less crop rotation across crops and hence similar crops with the same rooting character were grown year after year. There was almost no manure application to these fields except for farm no. 1, but farmers applied a small amount of chemical fertilizers for major cereal crops like teff and maize. In this system, crops like sweat potato are heavy nutrient miners not only because of their low contribution to the soil but also because of the continual removal of the residue as a planting material, which is as valuable as the tuber.

Earlier work indicated that soil fertility decline in the outfields of this system is not only related to nutrient deficits but also to low soil water holding capacity amid very low organic matter content compared to the infields, which is less the 25% compared to the organic carbon in the homestead fields. There was a significant difference between the after effects of the nitrogen fixing legume, *Vicia dasycarpa* or the incorporation of the crop residue of the preferred crop, potato on wheat yield.

The vetch crop, under sown with potato produced about 5.7 Mg of green biomass in three month time while the biomass of potato was about 4.73 tonnes per hectare. When wheat was following the vetch crop, wheat yield was 60% higher than the control while wheat yield under potato biomass was 42% higher than the control (Table 18). There was no statistical difference between vetch and potato biomass effects while the difference with the control, in both cases, was significant. This result was also confirmed by plant height measurements (Table 18), whereby both treatments were better than the control. However, farmer's ranking indicated that they prefer wheat after potato than the other treatments because of the possibly negative effect of vetch on the companion crop while growing in combination. Laboratory analysis for nutrients and water and also further field experimentation is planned for 2006.

Table 17. Land management history (crop sequence and fertilizer input) of degraded outfield of selected farms in the period of 2001 and 2005 of the research plot (100 m^2) in Areka.

	Farm types															
Year	**1**	**Inputs/ 100 m^2 plot**	**2**	**Inputs / 100 m^2 plot**	**3**	**Inputs / 100 m^2 plot**	**4**	**Inputs / 100 m^2 plot**	**5**	**Inputs / 100 m^2 plot**	**6**	**Inputs / 100 m^2 plot**	**7**	**Inputs / 100 m^2 plot**	**9**	**Inputs / 100 m^2 plot**
2001	Yam	Manure 50 kg	Maize and sweet potato	1 kg DAP	Wheat and sweet potato	4 kg DAP	Barley and Sweet potato				Teff and beans		Teff and beans	4kg DAP for Teff	Maize and sweet potato	1.5 kg DAP
2002	Maize and sweet potato		Maize and sweet potato		Maize	3kg DAP	Maize and pea	6 kg DAP for maize	Maize and potato	3 kg DAP	Wheat and sweet potato	6 kg DAP for wheat	Teff and beans	7 kg DAP	Beans and teff	3kg DAP
2003	Maize and taro	Manure 50 kg	Wheat	2 kg DAP	Wheat and sweet potato	3 kg DAP	Taro	60 kg manure	Fallow and barley		Teff and Sweet potato	6 kg DAP for teff	Teff and beans	7 kg DAP	Maize and sweet potato	2kg DAP
2004	Sweet potato and beans		Maize and sweet potato	1 kg DAP	Beans and wheat	6 kg DAP	Maize and pea	-	Sorghum		Teff and Sweet potato	6 kg for Teff	Teff and beans	7 kg DAP	Maize and sweet potato	2kg DAP
2005	Maize		Fallow				Beans	-	Fallow				Wheat	4kg DAP	Teff	1kg DAP

Table 18. The effect of Vetch or Potato residue biomass on the succeeding wheat crop in the degraded outfield of Gununo. n=8

Treatments	Biomass Yield (Mg ha^{-1})		Grain yield (Mg ha^{-1})		Farmers ranking; One being the best	Plant height	
	Mean	SE	Mean	SE	(1-5)	Mean	SE
Vetch green biomass	5.69	0.88	-	-	-	-	-
Potato residue biomass	4.73	1.18	-	-	-	-	-
Wheat under vetch	2.84	0.35	3.16	0.27	4.44	79.73	1.29
Wheat under potato	2.51	0.29	2.90	0.24	1.11	80.02	1.12
Wheat Control	1.77	0.21	2.15	0.23	3.89	72.20	1.69

Evaluation of best-bet options to combat Striga, stemborers and declining soil fertility in the Lake zone in East Africa

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Following PRA exercises in Kenya, farmers ranked Striga, stem borer and low soil fertility as the major constraints to maize production. Based on this, best-bet strategies for the suppression of Striga and stemborers and improvement of the soil fertility status were identified to be tested in farmer-participatory trials in Kenya, Uganda, and Tanzania.

Components of the best-bet strategies were improved cropping systems (‘push-pull’, rotations with grain (soybean) and herbaceous (*Crotolaria*) legumes), improved germplasm (herbicide-resistant maize), and fertilizer application. The ‘push-pull’ strategy uses trap- and repellent plants for management of stemborers. The trap plants, such as Napier grass (*Pennisetum purpureum)* are planted in a border around the maize fields, where invading adult moths become attracted to chemical emitted by the grass. These grasses provide the "pull" in the "push-pull" strategy. Plants that emit chemicals that repel the borers from the maize main crop provide the “Push” in the intercropping scheme. The borer repelling includes members of leguminous genus *Desmodium spp. Desmodium* is planted in between the rows of maize. It also helps maintain soil stability and improve soil fertility through its nitrogen-fixing action. *Desmodium* is easy to harvest and is as a highly nutritious animal feed. A ground cover of Desmodium, inter-planted among the maize, significantly reduces *Striga* growth. Certain legumes have been shown to trigger *Striga* germination without allowing them to grow. In the medium to long term, this suicidal germination may results in substantial *Striga* seed bank depletion in legume-maize rotations. Herbicide-resistant maize contains low doses of herbicide (e.g., 30 g imazapyr a.i./ha), as a seed coat. This manner of delivery act before or at the time of *Striga* attachment to the maize root and prevents the phytotoxic effect of *Striga* on the maize plant, which usually occurs even before *Striga* emergence. Additionally, imazapyr that is not absorbed by the maize seedling diffuses into the surrounding soil and kills non-germinated *Striga* seeds. Effects on *Striga*, stemborers, and soil fertility of these best-bet strategies were compared by using two maize varieties (herbicide-resistant maize and a local landrace or improved commercial variety) under two fertilizer levels (no fertilizer and medium fertilizer). Four demonstration sites were established in Vihiga and Siaya districts in the West of Kenya.

In Kenya, *Striga* emergence was significantly lower in the 'push-pull' system compared to other cropping systems in the 2nd, 3rd and 4th seasons (Figure 28). During the 3rd and 4th season, this reduction was also significant where IR-maize was planted.

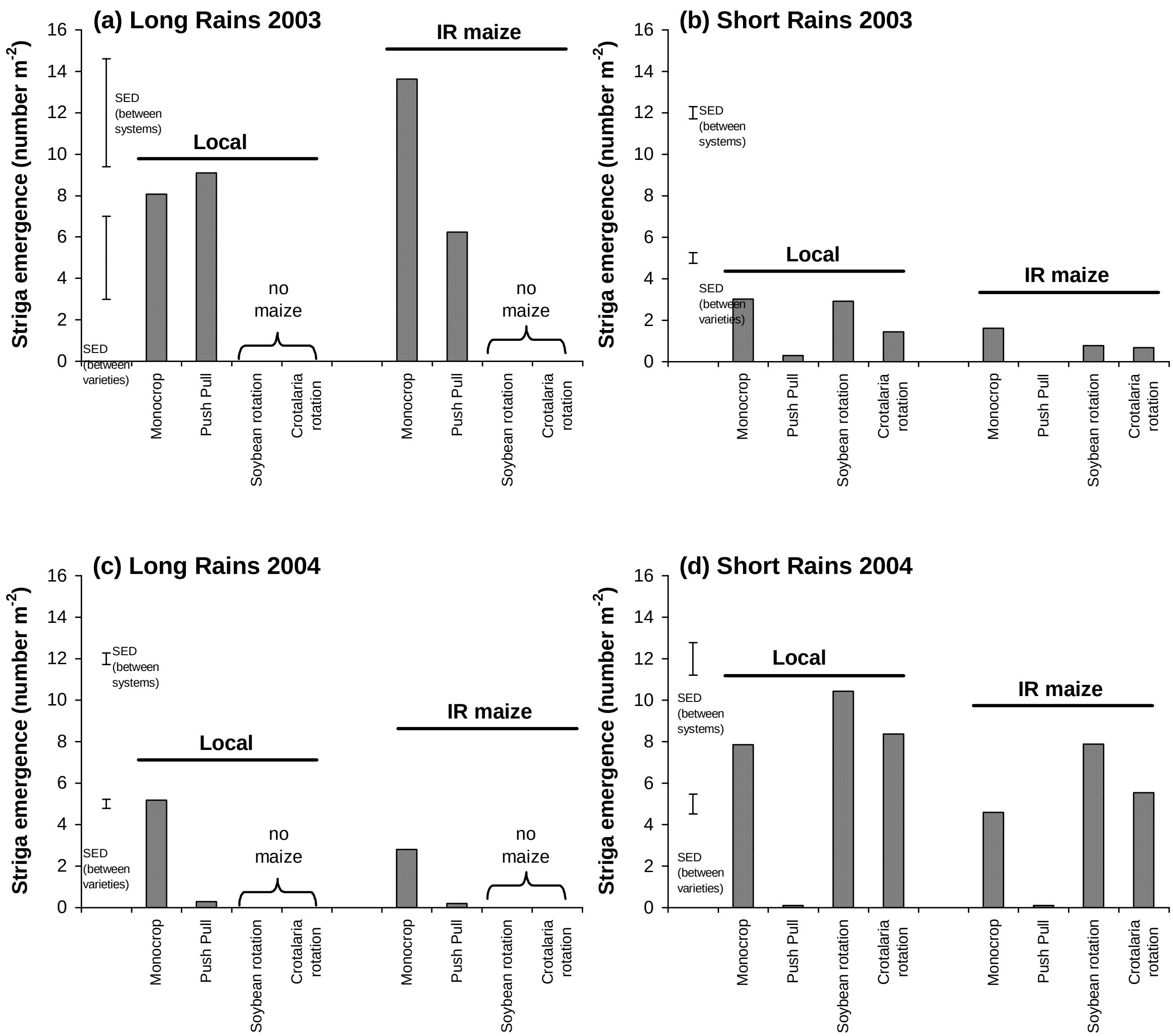

Figure 28. Effect of cropping systems and maize variety on *Striga* emergence in western Kenya. 'IR maize' refers to 'herbicide-resistant maize'.

There was no significant difference in stemborer infestation between districts during the long rains 2003 in Kenya, while in the short rains 2003, there was significant difference between districts with higher infestation in Siaya than Vihiga (Figure 29). Over the seasons, the 'push-pull' cropping system reduced stemborer damage more than any other cropping system in Siaya.

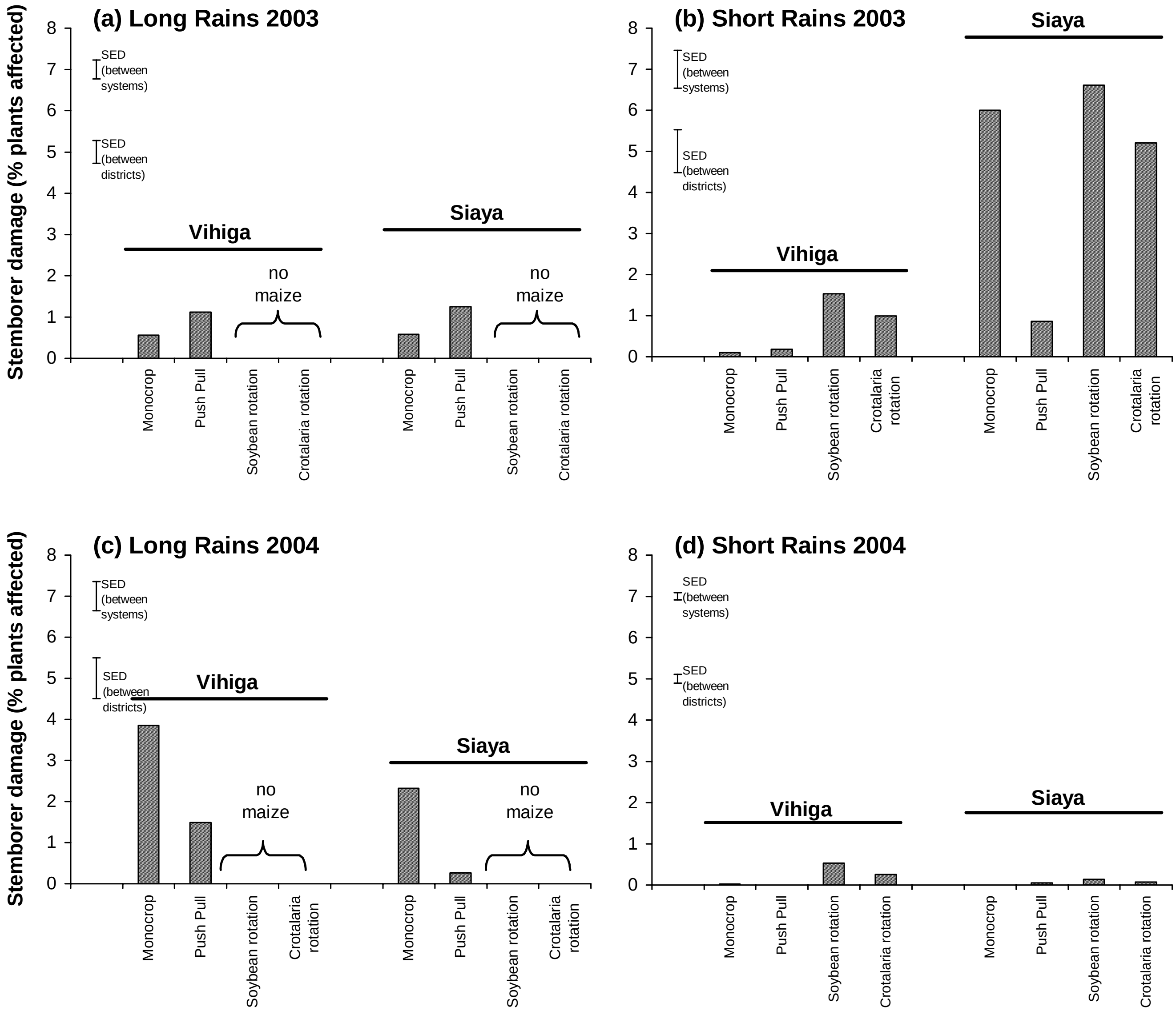

Figure 29. Effect of cropping system and maize variety on stem borer incidence in western Kenya. 'IR maize' refers to 'herbicide-resistant maize'.

Conclusions: The 'push-pull system' was observed to substantially reduce both *Striga* germination and stemborer damage. Herbicide-resistant maize reduced *Striga* germination only during specific seasons. Direct assessments of the Striga seedbank will reveal whether the rotations have effectively reduced the number of viable seeds in time.

Output target 2007

- ***Banana, bean and cassava-based systems, with the relation between pest, diseases and ISFM as entry point, including novel cropping sequences, tested and adapted to farmer circumstances in Africa***

Work in progress

Evaluation of the potential of arbuscular mycorrhizal fungi to enhance the initial growth of tissue culture bananas

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The tissue-culture is a promising technique to avail improved and homogeneous banana germplams to farmers. The current activity aims at identifying the best arbuscular mycorrhizal fungi (AMF) strains for inoculation of tissue culture bananas and quantifying the impact of such inoculation on banana survival, growth, and production. Specific objectives are (i) to assess the AMF-dependency of tissue culture bananas using existing AMF cultures, (ii) to determine the AMF diversity in banana plantations, and (iii) to identify the best indigenous strains for inoculating tissue culture bananas.

Arbuscular mycorrhizal fungi have the potential to improve the performance of tissue culture bananas in poor soils. The magnitude of response may vary between species and within species. Therefore, prior to establishment of tissue culture cultivars in poor soils, the response of different cultivars to different AMF isolates was determined. A greenhouse experiment was set up to determine the dependency of different tissue culture cultivars on different AMF isolates. Five desert bananas (Giant Cavendish, Williams Hybrid, Grand Nain, Gros Michel, and Dwarf Cavendish) were supplied by JKUAT, Nairobi, and plantlets of four cooking (Kisansa and Mbwazirume) and two desert (Mpologoma and Nakitembe) were supplied by Agrogenetics, Kampala. Four AMF inocula (*Glomus etunicatum*, *Glomus mosseae*, *Glomus intraradices*, and *Gigaspora albida*) were used. Mass production of the inoculum was done on sorghum grown in river sand. After inoculation with AMF, the tissue culture plantlets were grown in pots on river sand and nourished with modified Hewitt nutrient solution.

Banana growth was observed to be substantially enhanced after inoculation with *Glomus Etunicatum* and *Glomus intraradices*, followed by *Glomus mosseae* (Figure 30). *Gigaspora albida* did not influence banana growth.

Conclusions: Inoculation with AMF shows considerable potential to enhance the early growth of tissue-culture bananas, although observations after transplanting the plants under field conditions and observing their growth and production under field conditions is required before firm conclusions can be drawn. Fungi isolated from existing banana plantations could further outperform the strains used in the current trial, which is one of the follow-up activities currently being implemented.

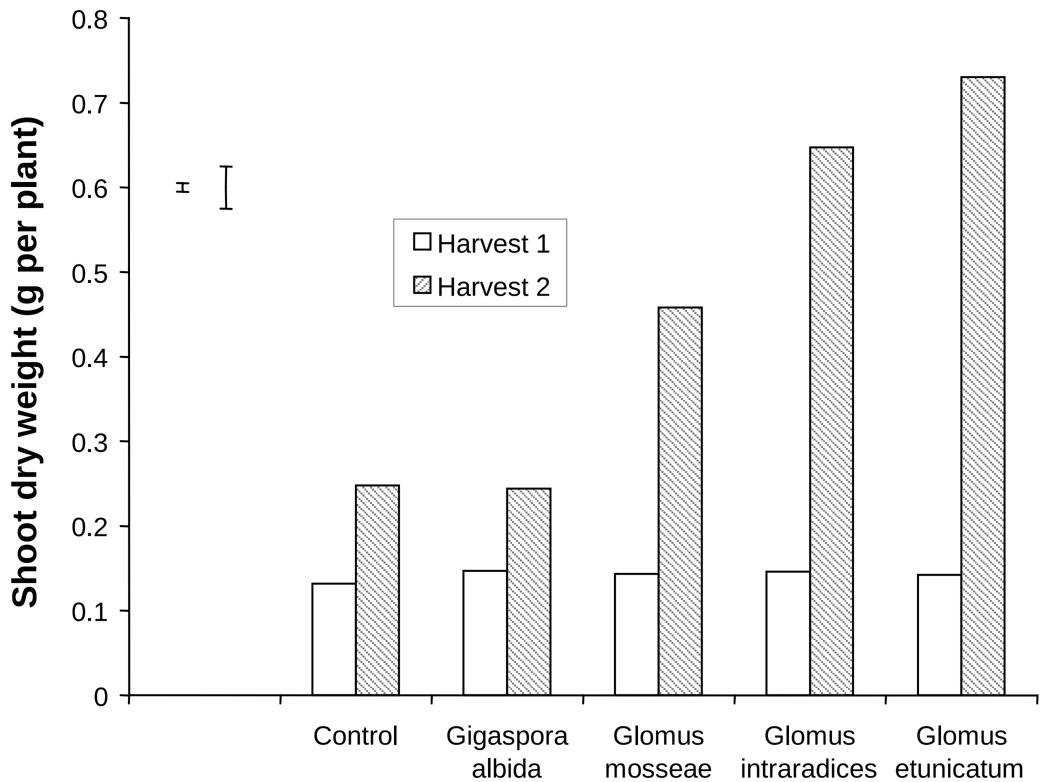

Figure 30. Shoot dry weight of different banana cultivars as affected by inoculation with different strains of AMF.

Determination of the most limiting nutrients for East African highland banana production, as affected by pest and diseases.

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[1]TSBF-CIAT; [2]IITA, Uganda; [3]JKUAT, Kenya

Although much soil fertility related studies in EA highland banana systems have been conducted, there is a lack of basic knowledge on how much nutrients the AAA-EA banana plant requires, what its potential production is under well fertilized conditions, what nutrients are limiting plant growth in different areas, and what how much fertilizer needs to be applied to achieve the economic optimum for a certain target yield (i.e. target yield will largely depend on pest and disease pressure) and market price. The objectives of the current activity are: (i) to identify what nutrients are limiting highland banana production on the trial sites, (ii) to determine what the nutrient requirements are of highland bananas, (iii) to identify/confirm what the critical and optimal nutrient concentrations are in different plant parts of highland bananas, (iv) to estimate potential production of highland cooking banana, and (v) to determine recovery rates of fertilizers in highland cooking bananas, in order to allow the calculation of cost-benefits of different fertilizer recommendations.

Trials, using a randomized complete block design with a set of mineral inputs x pesticide application treatments (Table 19), have been established in Maragua district in Kenya and in Ntungamo and Mpigi districts in Uganda. In Kenya, Cavendish, a popular desert cultivar, and in Uganda, Kisansa, a popular cooking cultivar is used as test crops.

Table 19. Treatment structure of the on-station nutrient omission trials.

Treatment	1	2	3	4	5	6	7	8	9	10
N	X	-	-	½	X	X	X	X	-	X
P	X	-	X	X	-	X	X	X	-	X
K	X	-	X	X	X	-	½	X	-	X
S + Micro-nutrients	X	-	X	X	X	X	X	-	-	X
Pesticide	X	X	X	X	X	X	X	X	-	-

After 4 months of growth (most of this period, bananas were irrigated), plant height and girth diameter were lowest for the no-input control treatments, both in absence or presence of pesticides (Figure 31). Significant responses to missing N, P, and S + micro-nutrients were observed for plant height and girth diameter. Pesticide application did not have a significant impact on plant growth at his early stage of banana growth. Interesting to note are the clear differences in leaf color as affected by not applying S and micro-nutrients, pointing at limitations of at least one of those nutrients.

Conclusions: Initial observations show significant enhancements in banana growth after application of specific combinations of nutrients. Crop yield data will be needed to measure the impact of specific nutrient stresses on final production. The representativeness of the site used for the trial will be assessed through comparing soil information from the current site with soil information from the banana plantation characterization work, carried out at an earlier stage of the project.

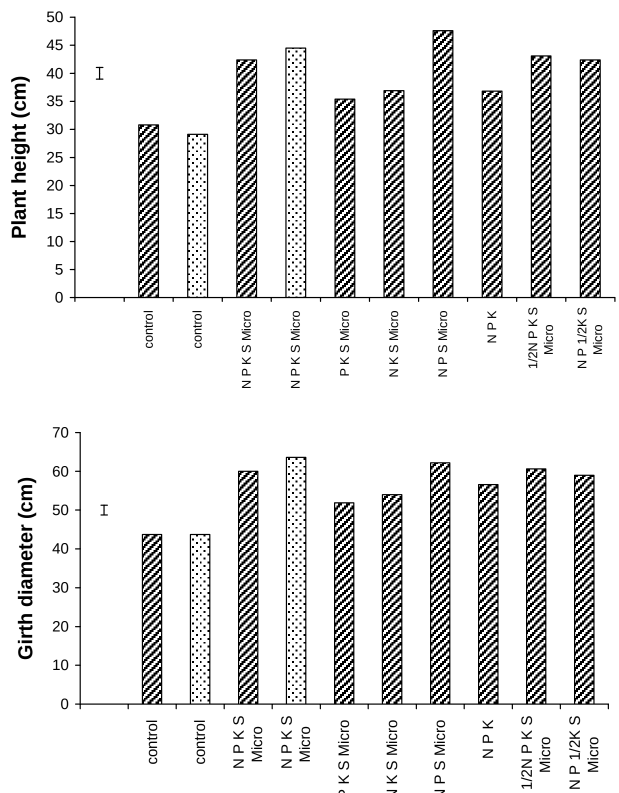

Figure 31. Plant height and girth diameter of 4-month old bananas at the Maragua on-station nutrient omission trial. Micro-nutrients used are Zn, Mg, B, and Mo. ‘1/2’ refers to half the application of that

specific nutrient. Bars with dots are treatments which do not receive pesticides to control weevils and nematodes, all other treatments receive pesticides.

Output target 2007

- ***Cereal-legumes and livestock systems, with nutrient use efficiency as an entry point, tested and adapted to farmer circumstances in acid soil savannas***

Work in progress

Residual effect of building an arable layer on maize yields
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TSBF-CIAT
The main objective of this work is to determine the residual effect of the construction of an arable layer on maize yields in the Easter Plains of Colombia. During a period of three years (2001 to 2004), a field experiment was conducted to investigate different strategies for the construction of an arable layer in a soil (Typic Haplustox Isohypertermic Caolinitic) of the flat Altillanura. For this purpose a randomized block experimental design with 13 treatments and three replicates was used. Native savanna (treatment 13) was used as control treatment. Experimental plots were of 40×41m. Treatments involved three factors: 1) three different sequences of crop rotations (Table 20), 2) two sources of calcium and magnesium (dolomitic lime and sulcamag), and 3) two depths of tillage with rigid chisels (0-15; 0-30 cm).

Table 20. Sequences of crops established for the construction of arable layer from 2001 to 2003.

Crop sequences No	Year 2001		Year 2002		Year 2003
	Semester A	Semester B	Semester A	Semester B	Indicators crops
1	Rice Line 30	Rice Line 30	Maize H-108	Millet + Legumes (*)	Maize H-108 vs (MHY) (***)
2	Rice Line 30 + *B. brizantha*	*B. brizantha* (**)	Maize H-108	Soybean P-34	Maize H-108 vs (MHY) (***)
3	Rice Line 30 + *B. brizantha* + *D. ovalifolium*	*B. brizantha* + *D. ovalifolium*	Maize H-108	Millet + Legumes (*)	Maize H-108 vs (MHY) (***)

* Forage legumes = *Pueraria phaseoloides* + *Desmodium ovalifolium*
** Forage grass = *Brachiaria brizantha*
*** (MHY) = Maize with high yield potential

Table 21 shows the treatments. Depth of tillage was initially (0-15cm) in the first year and became deeper (0-30 and 0-45cm) in the second year. This decision was taken, because soils are very hard and it is not advisable to force the soil to be broken down by chisels or to damage the chisels. So a gradual improvement of soil with depth was planned.

The criterion for the application of the lime was to apply a quantity that is enough to achieve a calcium + magnesium saturation of 70% in two years at the respective soil depths of improvement. The quantity of lime to be applied was split into two applications, 50% at the beginning of the first year and 50% at the beginning of the second year.

Table 21. Details on the distribution of soil amendments by crop sequences and depth of tillage.

Treatment No	Crop Treatment No	Crop sequences No	Depth of tillage (cm) Year 2001	Year 2002
1	1	100% lime	0 to 15	0 to 30
2	1	75% lime + 25% Sulcamag	0 to 15	0 to 30
3	1	100% lime	0 to 30	0 to 45
4	1	75% lime + 25% Sulcamag	0 to 30	0 to 45
5	2	100% lime	0 to 15	0 to 30
6	2	75% lime + 25% Sulcamag	0 to 15	0 to 30
7	2	100% lime	0 to 30	0 to 45
8	2	75% lime + 25% Sulcamag	0 to 30	0 to 45
9	3	100% lime	0 to 15	0 to 30
10	3	75% lime + 25% Sulcamag	0 to 15	0 to 30
11	3	100% lime	0 to 30	0 to 45
12	3	75% lime + 25% Sulcamag	0 to 30	0 to 45
13	Savanna	Control	No amendment	No amendment

* Lime = 56% de $CaCO_3$ and 34% of $MgCO_3$ (Sieved in 100 MESH)

Sulcamag = 61% of $CaSO_4$ and 39% of $MgSO_4$

Sequence 1 emphasized soil physical improvement with more lignified crops (Rice and millet). Sequence 3 emphasized on organic and biological improvement working with materials of better quality (grass and Legumes). The sequence 2 was an intermediate strategy (Table 20). Lime and sulcamag as soil amendments were incorporated with chisel only for the crop of the first semester every year. Second semester crops were sown with a direct drilling machine. Fertilization was done in accordance with the recommendations for the region. When necessary, control of insects, diseases and weeds was done.

After three year of evaluations, it was concluded that in all treatments implemented to build up an arable layer, physical and chemical soil constraints were overcome in relation to native savanna and that maize yields, did not show significant differences between the treatments. Average yields of maize varied between 6,475 and 7,406 kg ha^{-1} in the 0-30cm soil depth and between 6,121 and 7,448 kg ha^{-1} when the depth of chisel was 0-45cm depth. The combination of lime + sulcamag was better than the application of lime alone.

During year 2004 no land preparation was made in the experimental area, but kudzu was sown and left to protect the soil. Dry matter of this species reached values that varied between 11 to 13 Mg ha^{-1}. At the beginning of the rainy season of 2005 *Pueraria phaseoloides* was eliminated and maize was sown under the system of direct drilling. Fertilization was calculated on the basis of the amount of nutrients needed to produce seven tons of maize grain yield per hectare. The quantities used were: 150, 64, 140, 0.4 and 2 kg/ha of N, P_2O_5, K_2O, B and Zn respectively. Atrazine was applied after sowing for control of weeds. Maize seed of (Pioneer hybrid 3041) was sown placing six seeds per a length of one meter in a row.

Table 22 shows the yields obtained in maize. There were no significant differences between treatments, showing that there was a good residual effect of the building up of the arable layer and that it is possible to produce high yields using the concept. The yields obtained were the double or triple of the yields obtained under traditional systems (1500-2500 kg ha^{-1}). If maize is sown in savanna soils without any land preparation, soil amendment (lime) or fertilizers, it is not possible to produce maize in these soils.

Table 22. Grain yields of maize in 2005 with different treatments used to construct arable layer.

Crops sequences	Maize yields (kg/ha)			
	Depth 0-30 cm		Depth 0-45 cm	
	Lime	**Lime+Sulcamag**	**Lime**	**Lime+Sulcamag**
Crop rotations	6475	6515	6121	7349
Crops + grass	6765	6921	6539	7448
Crops + grass + legumes	6631	7406	6816	7368

Output target 2008

- ***Communities in at least three countries demonstrate and test direct or indirect management options that enhance locally important ecosystem services using BGBD***

Published work

R. Duponnois[1] and D. Lesueur[2] (2005) Sporocarps of Pisolithus albus as an ecological niche for fluorescent pseudomonads involved in Acacia mangium Wild – Pisolithus albus ectomycorrhizal symbiosis. Canadian Journal of Microbiology 50: 691-696
[1]IRD/Burkina Faso; [2]TSBF-CIAT
Fresh sporocarps and root and soil samples were collected under a monospecific forest plantation of *Acacia mangium* in Dagana in Northern Senegal and checked for the presence of fluorescent pseudomonads. No bacteria were detected except from sporocarps collected with adhering soil and hyphal strands. *Pisolithus* sporocarps were dried at 30 °C for 2 weeks, ground, passed through a 2-mm sieve and mixed together. This dry sporocarp powder (DSP) was used to inoculate and form mycorrhizas on *A. mangium* seedlings in a glasshouse experiment. After 3 months culture, plant growth was increased in the DSP treatment but no ectomycorrhizas were present on the *A. mangium* root systems; however fluorescent pseudomonads were recorded in the cultural soil. The stimulatory effects on the plant growth were maintained for 6 months. However, fluorescent pseudomonads were no longer detected and 35% of the short roots were ectomycorrhizal. Some of the fluorescent pseudomonad isolates detected after 3 months stimulated the radial fungal growth in axenic conditions. These observations suggest that these bacteria are closely associated with the *Pisolithus* fructifications and could interact with the ectomycorrhizal symbiosis establishment.

Work in progress

BGBD project
The demonstration of direct and indirect management options for the conservation of BGBD and enhancement of ecosystem services is subject of the second phase of the project. In 2005 the various countries have made a first attempt to identify relevant management option for consideration during the second phase. These may include use of *Trichoderma* and *Bacillus thuringiensis* as agents of biological control of pest and diseases, and push-pull approached in combination with crop rotation also in view of control of pest an diseases to name two options considered by the Kenyan BGBD team as examples. In general the ecosystem services targeted will concern soil structure modification and improved soil water balance, pest and disease control, nutrient cycling and soil fertility enhancement and carbon sequestration and reduction of greenhouse gas emissions.

Output target 2008

- ***Quesungual and other related agroforestry systems, with soil and water conservation as entry point, including crop diversification strategies, tested and adapted to farmer circumstances in Central America***

Work in progress

Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the sub-humid tropics

E. Amézquita [1], M. Ayarza[1] , E. Barrios [1], I.Rao, M. Rondon [1], A.Castro [2], M. Rivera [2], O. Ferreira [2], O. Menocal [3], Z. Martinez[4], I. Rodríguez [5] and G. Bonilla [5]
[1]TSBF-CIAT, [2]Project students, [3] INTA,Nicaragua; [4] ESNACIFOR, Honduras; [5]Universidad Agraria de Nicaragua, Nicaragua

The Quesungual Slash and Mulch Agroforestry System (QSMAS) has contributed to a successful development strategy in improving rural livelihoods in the Lempira Department, Honduras. This alternative to slash and burn agriculture strongly builds on local knowledge and has been a major production system to achieve food security by resource poor farmers. The widespread adoption of the QSMAS by more than 6,000 farmer households has been driven by a two-fold increase in crop yields and cattle stocking rates and significant reduction in costs associated with agrochemicals and labor. Farmers recognize that a remarkable feature of the QSMAS is the increased soil water holding capacity and extended time of soil water availability thus preventing crop failures. Besides making a substantial contribution to food security, QSMAS has shown a remarkable degree of resilience to extreme water deficits and also to excess water during natural catastrophes.

In 2004 the Water and Food C.P approved financial support to determine the key principles behind the social acceptance and biophysical resilience of QSMAS. The specific objectives of the project are: 1) To assess socioeconomic and biophysical context of QSMAS; 2) To define QSMAS management concepts and principles and to develop relevant tools to monitor soil and water quality; 3) To evaluate and document potential areas suitable to QSMAS and 4) To develop tools for dissemination, adaptation and promotion of the QSMAS management strategies.

The target area is characterized by steep slopes >40%, shallow soils (Entisols) with low pH (<5.1) and generally with low amounts of available phosphorus. Annual precipitation is about 1400 mm (target region of <900 m.a.s.l.) and the rainy season lasts from early May to the end of October with a long dry season of up to six months. The extent of water deficit in the middle of the dry season is over 200 mm. The average annual temperature varies from 17 to 25°C. During the dry season from early November to April, strong winds blow from the North and the enhanced evapotranspiration rates cause a severe water deficit until the onset of rains.

Field research is being conducted with strong participation of the MIS consortium in Central America, a network of biophysical and socioeconomic researchers and extension agents from NARES and universities from Honduras and Nicaragua.

Expected outputs of this work will be***:*** 1) **Principles** regulating soil-water cycle and C storage in QSMAS understood and applied to other similar regions in pilot watershed areas of Honduras and neighboring countries; 2) **tools**, methodology and data sets relevant to quantify water quality and availability at plot, farm and landscape levels; 3) **Scenarios** of impact of intensification and diversification processes on water quantity and quality of the adopted QSMAS for the upstream and downstream users; 4) Increased farmer's **income** by 20% to 30% through QSMAS-driven enhanced water availability and use efficiency;

5) **Cleaner water** (water with few sediments) produced for downstream users (human and animal consumption), as an added QSMAS environmental service and 6) **Trained personnel** from National Programs and NGOs in the use of field methodologies to assess water quality and soil water storage capacity.

Preliminary results

Table 23 shows the main outcomes of the work during the first year of the project. In general, QSMAS is inserted in the landscape within a mosaic of natural tree vegetation at different stages of regrowth because of the elimination of burning in the region. Soil losses are negegible and water conservation is increased because of permanent mulch on the soil. Preliminary results are showing that soil losses under QSMAS of different ages (2, 5 and >10 years), were less than 2 Mg ha^{-1} in 14 weeks in comparison to the 30 Mg ha^{-1} losses observed in the slash and burn treatments. Excess water leaving the system by runoff is almost clean and can be used by downstream users. However, there are methodological challenges to determine water dynamics in the soil because of the high proportion of stones in the soil. Crop yield data is indicating that there is a strong interaction between soil fertility, water availability and crop productivity.

Table 23: Main outcomes of the project during the first year of the QSMAS project.

Project output/s	Main outcomes
1. Socioeconomic and biophysical context of QSMAS assessed and information assembled into a data base.	• A Digital elevation model of the area of influence of the QSMAS developed containing information on slope, land use, climate and altitude. • Collection and analysis of available socioeconomic information. • Main farm typologies identified with emphasis on water driven processes.
2. QSMAS management concepts and principles defined and relevant tools developed to monitor soil and water quality.	• Definition of research protocols and methodologies. • Selection of farms to study the plant, soil, water and gas components of QSMAS. • Establishment of the field experiments to asses the effect of soil fertility and QSMAS age on crop productivity. • A better understanding of the system at plot, farm and landscape level. • Allometric equations developed to estimate biomass and carbon accumulation of dominant trees in the system.
3. Potential areas suitable to QSMAS evaluated, analyzed and documented.	• Participatory selection of the Somotillo region in Nicaragua to validate the QSMAS • Establishment of six on-farm validation plots to compare QSMAS against traditional management systems.
4. Tools for dissemination, adaptation and promotion of the QSMAS management strategies developed.	• Farmer to farmer exchanges, field tours and periodic press releases. • 3 MIS Bulletins prepared highlighting progress on project implementation. • Identification of 2 PhD, 2 MSc and 6 BSc candidates from the region

Progress towards achieving output level outcome

- *Technologies, systems and soil management strategies adopted and adapted through partnerships*

In Output 2, the main objective is to develop and adapt technologies and soil management strategies that are encompass the various principles and concepts developed in Output 1, through partnerships with all stakeholders. This development and adaptation process includes various phases with increasing direct involvement of farming communities and other stakeholders. During the initial phases, knowledge, often derived from detailed literature reviews, is translated in soil management practices with relatively little involvement of stakeholders. As technologies move away from the design phase to the farmer's fields, farmers and other stakeholders gradually take over the evaluation and adaptation process.

Most reports under Output 2 deal with the development of testing of a decision framework for ISFM and with the testing and adaption of cereal-legume-livestock systems in Africa. As for the former set of activities, results are reported that relate to the site-specific management of resources (e.g., legume biomass, P, manure) at the farm-level, taking into account variability at the natural resource status and community level. As for the latter set of activities, a substantial number of abstracts summarize detailed reviews of the role of manure in soil fertility maintenance and of soil fertility management strategies for West, East, Central, and southern Africa. Other specific activities relate to the identification and utilization of specific production niches at the farm level, such as, niches for green manure production in Ethiopia, or vegetable gardens in Kenya. Cotton-cowpea systems in Zimbabwe, legume-based striga control technologies in Kenya, Uganda, and Tanzania, and soybean varieties in Kenya are being evaluated using participatory approaches. Finally, certain abstracts have investigated the success and failures of specific soil fertility management options, evaluated through community-based learning process and collective and individual experimentation.

The development and evaluation of technologies aiming at improving the productivity of banana and cassava-based systems in Africa and cereal-legume-livestock systems in Latin America have just reached the initial design phase with promising initial results related to nutrient management of bananas and inoculation of tissue culture bananas with arbuscular-mycorhizal fungi. The evaluation of direct and indirect management options of belowground biodiversity and the Quesungual agroforestry systems has also just been initiated with some preliminary ex-ante evaluation of the latter.

Progress towards achieving output level impact

- *Adapted technologies contribute to food security, income generation and health of farmers*

In Output 2, only the cereal-legume-livestock systems have reached a stage that impact of adoption of such technologies will contribute positively to food security, income generation and health of farmers. This initial adoption phase will be followed in future activities. As for the other technologies and entry points, an evaluation and adaptation phase is required before any impact can be expected.

Output 3
Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils

Output 3: Partnerships and tools developed and capacity enhanced of all stakeholders for improving the health and fertility of soils

Rationale

Managing soil fertility for improved livelihoods requires an approach that integrates technical, social, economic, and policy issues at multiple scales. To overcome this complexity, research and extension staff need the capacity to generate and share information that will be relevant to other stakeholders working at different scales (i.e., policy-makers, farmers). Thus the activities of Output 3 are founded on building the human and social capital of all TSBF-CIAT stakeholders for research and management on the sustainable use of tropical soils.

The challenge of building the social capital encompasses both the new and existing networks of scientists and other stakeholders (e.g.: AFNET, MIS, CSM-BGBD project). Within these networks, as within the individual project activities where TSBF-CIAT works in partnership with others (NARES, ARI's, NGO's), building social capital means ensuring that communication and co-learning support effective institutional collaboration and build confidence in the collaborative advantage afforded by partnerships. Networks run best with diligent coordination that responds to internal and external challenges. However, partnerships become truly empowering when stakeholders themselves recognize and exploit research and development opportunities. The activities prescribed here envisage tapping the potential of South-South collaboration and establishing strategic partnerships that can build learning strategies that to institutionalize ISFM approaches.

The second challenge, of building human capacity, is particularly acute in sub-Saharan Africa and Central America, where the lack of strong tertiary education systems and the chronic under-funding of NARES hamper the professional development of many of our partners. Since ISFM approaches are inherently holistic, effective training demands interdisciplinary cooperation to instill both a specialized knowledge and a competent understanding of the context(s) in which to apply it (the so-called "T-shaped" skill set). Again, working through new and existing networks and partnerships, TSBF-CIAT will continue to support training that offers cutting-edge bio-physical science, laboratory techniques, and also embraces holistic understanding of social, cultural, economic, and policy issues related to soil fertility management.

Building human capacity also applies to the relationship land users have with the products of research. At present, many ISFM technologies remain little used by farmers. This is commonly conceived of as a failure to disseminate the results of research, but can also be seen as indicating a fundamental failure of research to recognize, value, and address farmers' conditions and knowledge. Greater involvement of farmers in the technology design process (to adapt solutions to actual conditions) will not only generate more relevant and adoptable ISFM technologies but is also expected to facilitate the potential dissemination and up-scaling of these technologies through the better interaction and integration of indigenous and formal knowledge systems.

Finally, the lack of an enabling policy environment is made manifest by the often-contradictory policies relating to farm, village, or regional-level conditions. The poor functioning of local input and output markets distorts the incentives for resource conservation. Coherent policy options are needed to address the low added value of farmers' products, the general lack of marketing opportunities on the one hand, and the lack of appropriate infrastructure and mechanisms for input delivery on the other.

Key research questions

1. What are the mechanisms and information required for institutionalization of ISFM approaches with partners for scaling-up and increased impact?

2. Who are the key stakeholders and partners for SLM?
3. What are the relevant learning processes and approaches to improve stakeholders' skills to make improved decisions?
4. How can South-South integration facilitate the development of global products?

Milestones 2005

- ***AfNet, MIS, SARNET and BGBD Networks restructured and strengthened***

AFNET: Following the Yaoundé Symposium in 2004 and in view of continuing growth in membership across sub-Saharan Africa, the network has implemented a structure based on multidisciplinary, regional teams. These teams are now actively involved in proposal development and research implementation

MIS: The network remains focused on the poorest and most degraded environments of Central America (Honduras, Nicaragua) with special emphasis on the Quesungual agroforestry system. It was agreed at the Scientific Advisory Committee meeting (June 2005) that there was no advantage to moving forward with expanding MIS into a "Latin America network" (LATNET) along the lines of AFNET.

BGBD and ***SARNET:*** The successful completion of Phase 1 of the BGBD project culminated in preliminary results being presented at the Annual meeting in Manaus, Brazil (April 2005). At this meeting, and with the input of the Phase 1 evaluation team, mechanisms and communication pathways were prepared to improve information sharing and publication. SARNET (South Asia network) remains the umbrella affiliation that links the Indian country team members in implementing the BGBD work. Major achievements included the participation of seventy four participants of the project from across all the countries in the project and the participation of the project advisory and steering committees in the same meeting. Suggestions were made by both the project advisory committee (PAC), the Technical Advisory group (TAG) and the project steering committee (PSC) on matters that will strengthen the project as a way forward in addressing the expected outcomes of the project. Some of the suggested action lines included:

1. *Actions to ensure that there is a consistent quality and quantity of inventory data across the sites:* The extent of completion of the agreed inventory was observed to be different between sites – in some cases due to lack of expertise. It was observed that the project needed to provide the appropriate advice and capacity building to ensure consistency in methods and data quality and quantity across the sites.
2. *Application of consistent analyses and hypothesis testing to the inventory data in all countries:* It was observed that by the time of the annual meeting in Brazil (April, 2005), most analyses of results had been confined to testing the relationship between diversity and land use type or intensity. The scope of analysis and synthesis needed to be widened and the statistical rigour improved. Many suggestions in these respects were provided.
3. *Establishment of a meta-database and across-site synthesis of the data:* An observation on data was that once data are synthesized at a national level, an exciting opportunity emerges to conduct cross-site and country analyses and syntheses to achieve the 'global' products contracted by UNEP and GEF. The project needed to put in place the mechanisms for doing this which will take into account the intellectual property rights of all participants. A discussion paper on data sharing, publishing and intellectual property rights was presented and discussed during the meeting and a way forward agreed upon.
4. *Restructuring and strengthening of the BGBD project:* On restructuring of the BGBD project, it was agreed the current project implementation set up having working four groups be re-structured and a new strategy adopted that would achieve better results. This was part of the outcome of the project mid-term evaluation team. Another recommendation by the mid-term evaluation consultants was that TSBF takes up more responsibility in the scientific leadership of the project

to give it the edge in ensuring outcomes of the project are achieved during the second phase of the project. The coordination of the project in the countries was also addressed. It was agreed that the country project coordinators should be able to spend at least 50% of their time in project activities, otherwise they step aside and somebody able to spend that kind of time appointed coordinator. There was also a recommendation that quantifiable verifiable indicators be included in the project log-frames to provide the basis for monitoring and evaluating the project in the future. The global coordinating office (GCO) is in the process of restructuring and reorganizing the project according to the recommendations of the mid-term evaluation and according to the recommendations of the PAC in consultation with UNEP.

Highlights

- Commercial farms implemented with conservation farming practices in Fuquene watershed have been at the threshold level to enhance farmer to farmer and technician to farmer knowledge sharing in the Andean region.
- Partners during the BGBD annual meeting produced a total of 71 papers and four discussion papers in ecosystems services, land use intensity quantification, economic valuation of BGBD and data sharing and intellectual property rights.
- AFNET researchers prepared a total of 6 journal articles, 3 book chapters and 11 other publications.
- Results from the use of the NuMaSS (nutrient management expert system) to improve N management in maize-based systems in Nicaragua and Honduras indicated that improved fertilizer N recommendations require knowledge of both the intended crop cultivar and field site characteristics.
- The intensive exchange of ideas and experiences between farmers from Honduras and Nicaragua has accelerated the dissemination of the Quesungual system in drought-prone regions of Nicaragua.
- BGBD scientists participated in three global training workshops. Two in Nairobi (ants and termites characterization) and one in India on mycorrhizal fungi.
- Individual countries organized workshops and training courses for their country partners and project executioners.

Output target 2006

➢ ***At least two capacity building courses on ISFM held***

Completed work

Africa Network (AfNet)
Two intensive short-term trainings courses for AfNet scientists were conducted in 2005. Also, a third conference was jointly organized between AfNet and IAEA on land degradation.

1. **Participatory Approaches to Research and Scaling Up, an AfNet Training Workshop funded by CTA and held at the World Agroforestry Centre, Nairobi,**

This was the second training of AfNet scientists in farmer participatory research (FPR) methods and scaling up (SU). The 37 participants (in the two week training were AfNet Natural Resource Management scientists from West Africa (Nigeria, Burkina-Faso, Ghana, Niger and Senegal), Central (DRC) East Africa (Kenya, Uganda and Tanzania) and Southern Africa (Malawi, Zimbabwe,) as well as Madagascar (Table 24). There were scientists both first language Anglophones as well as Franco-phones, and the individual disciplines included rangeland ecologists, soil scientists, anthropologists, agro-foresters, sociologists, and one economist. The training covered key concepts and tools for applying farmer participatory methods and approaches to natural resource management research. With the use of one field trip at the end of the first week, participants applied the learning of participatory approaches directly with Farmers in the Meru District of Kenya.

The workshop was opened by the AfNet Program Coordinator, Andre Batiano, who also made presentations on behalf of R Tabo Deputy Director – Western and Central Africa, ICRISAT and Nteranya Sanginga Director, TSBF-CIAT. The workshop was organized and facilitated in terms of content by Ritu Verma, a social scientist and anthropologist at TSBF-CIAT. It was also assisted by other content facilitator, including Michael Misiko, also an anthropologist at TSBF-CIAT, and five invited presenters:- Sandra J. Velarde , Programme Officer, ASB, Regina Karega, Kenyatta University, Elly Kaganzi, Regional Agroenterprise Specialist, CIAT, Jonas Chianu Economist, TSBF-CIAT, Pascal Sanginga, Sociologist, ERI-CIAT. The workshop had three facilitators who mainly focussed on process, and these included Sue Canney Davison, (Pipal ltd Nairobi) and Twalib Ebrahim and Ezekiel Nguyo form the Depot (an NGO based in Nairobi).

Table 24. List of participants trained in the Participatory Approaches to Research and Scaling Up, Nairobi Kenya 2005.

Name	Country	Name	Country
Abdoulaye Moussa	South Africa	Linus Wekesa	Kenya
Amadou Fofana	Senegal	Loraine van den Berg	South Africa
Anthony Esilaba	Kenya	Luke Abatania	Ghana
Benedict Kayombo	Botswana	Mamadou Gandah	Niger
Boaz waswa	Kenya	Mary Baaru	Kenya
Daniele Ramiaramanana	Madagascar	Mathias Fosu	Ghana
Dougbedji Fatondji	Niger	Millogo Sorgho-Claire	Burkina Faso
Dr. Christogonus K. Daudu	Nigeria	Moses Munthali	Malawi
Elizabeth Barirwa	Uganda	Moussa Bonzi	Burkina Faso
Fresiah Mwebia	Kenya	Mr. Ado A. Yusuf	Nigeria
David Muchiri	Kenya	Nancy Mungai	Kenya
Hamade Sigue	Burkina Faso	Njingulula Mumbeya	DRC

Hassane Ousmane	Niger	Rebecca Zengeni	Zimbabwe
Joseph Mudiopo	Uganda	Rodger Kanton	Ghana
Justin P Muriuki	Kenya	Seraphine Kabore	Burkina Faso
Khumoetsile B Mmolawa	Botswana	Victor	Madagascar
Lawarnou	Niger	Zaid Mkangwa	Tanzania
Lee Simons	South Africa	Zivayi Magadzire	Zimbabwe
		Isaac Ekise	Kenya

2. Advanced DSSAT4 Training Workshop: Assessing Crop Production, Nutrient Management, Climatic Risk and Environmental Sustainability with Simulation Models, M Plaza Hotel, Accra, Ghana, Oct. 21 – 29, 2005

This training, Jointly organized by Project 5 of the Challenge Program on Water for Food (ICRISAT), the African Soil Biology and Fertility Network (TSBF-CIAT), and the Desert Margins Program (CGIAR) was presented by the International Consortium for Agricultural Systems Applications (ICASA). This training was a follow-up of one held in 2004, in Arusha, Tanzania where a team of 30 sceintists was to familiarized with DSSAT, a comprehensive computer model for the simulation of crop growth and yield, soil and plant water, nutrient and carbon dynamics and their application to real world problems. The specific focus of the follow-up training was to advance the target scientists' knowledge of the full capabilities of DSSAT through own data simulations and interpretations. The workshop aimed at:

- Refreshing participants on minimum data requirements for DSSAT version 4 and the procedures for collecting and managing weather, soil, crop and management data for model evaluation.
- Giving participants the opportunity to work with their own datasets and determine the accuracy of the models for application to specific problems.
- Participants using own data to analyze management alternatives for single or multiple seasons, or over long-term crop rotations.
- Participants assessing economic risks and environmental impacts associated with agricultural production.

Training participants on how to use DSSAT with socio economic analysis to link on-farm information with biophysical models: The training was done at personal levels with participants being assisted individually whenever one had a hands-on problem. For the issues that cut across the whole group, short lectures, demonstrations were used. Group sessions were conducted where participants reported to the whole group about their progress on given model issues. The workshop brought together 28 participants from 10 different countries namely; Niger, Senegal, Burkina Faso, Kenya, Uganda, Togo, Ghana, Japan, France and Mozambique (Table 25), 11 of whom attended the training for the first time. There were six trainers namely professor James W. Jones from University of Florida (USA), Professor Gerrit Hoogenboom from University of Georgia (USA), Dr Paul Wilkens from IFDC-Alabama (USA), Dr Ken Boote, Professor from University of Florida (USA), Pierre C. Sibiry Traore from ICRISAT-Mali and Dr Jetse Stoorvogel from Wageningen, the Netherlands.

Table 25. List of participants of the Advanced DSSAT4 Training Workshop, M Plaza Hotel, Accra, Ghana, Oct. 21 – 29, 2005.

Name	Institution	Country	Name	Institution	Country
Adamou Abdou	ICRISAT	Niger	Nyambane Nyanga'u	Kenyatta University	Kenya
Cheich Lô	ISRA/ CDH	Senegal	Michiel De Vries	WARDA	
Ousmane Hassane	ICRISAT	Niger	Stephen Kimani	KARI	Kenya
Sigue Hamade	INERA	BF	Boaz Waswa	TSBF	Kenya
Korodjouma Ouattara	INERA	BF	Jules Bayala	INERA	BF
Boubie Bado	WARDA	BF	Anthony Esilaba	KARI	Kenya
Dr. Roger Kanton	SARI	Ghana	Joseph Miriti	KARI	Kenya
Dr. Saaka Buah.	SARI	Ghana	Jacinta Kimiti	KARI	Kenya
Wilson A Agyare	SARI	Ghana	Dougbedji Fatondji	ICRISAT	Niger
Seraphine Kabore	INERA	BF	Akira Kamidohzono	JIRCAS	Japan
Moussa Bonzi	INERA	BF	Joy Tumuhairwe	PLEC/ MUK	Uganda
Karim Traore	INERA	BF	Marc Corbeels	CIRAD	France
Ms. Dilys S. KPongor	ZEF	Ghana	Hellen Wangechi	TSBF	Kenya
Mathias Fosu	SARI	Ghana	Job Kihara	TSBF	Kenya

3. Combating soil degradation to enhance food security in Africa: The role of nuclear techniques in developing improved soil, water and nutrient management practices, 10-12 October 2005, Nairobi, Kenya

This international conference was jointly organized by FAO/IAEA Division, AfNet and Kenyatta University. Conference, attended by 20 participants, focused on the use of isotopic tracers and soil moisture neutron probes to quantify stocks and flows of nutrients, water and soil in cropping systems. The objectives of the meeting were (1) to review recent advances in the use of nuclear and related techniques for developing integrated soil, water and nutrient management practices to combat land degradation an desertification; (2) to enhance knowledge and awareness of the potential of nuclear and related techniques to obtain unique information to enable formulation of integrated strategies to combat land degradation at national and regional scales and (3) to provide a forum for participants to exchange ideas and experiences and establish linkages for future collaboration. The specific issues addressed were desertification, nutrient mining and replacement, carbon sequestration, soil acidity, soil salinization, water management soil erosion and sedimentation. Its approach was mainly presentation of technical papers on these issues and group discussions.

Network research sites in 2005

In Africa, trials were continued at representative benchmark sites in some important agro-ecological zones. Table 26 below shows a list of Network collaborative trials in Africa, giving the type of trial and sites located.

Table 26. Network collaborative trials in 2005.

Type of Trials	Site	Country
Long-term operational scale research	5 sites	Niger, Burkina Faso, Nigeria, Togo and Kenya
Long-term cropping system	Sadore	Niger
Long-term crop residue management	Sadore	Niger
On-farm evaluation of cropping systems technologies	3 sites	Niger, Tanzania, Kenya
On-farm evaluation of soil fertility restoration technologies	Karabedji, Gaya	Niger
Methods of P and manure application	Karabedji	Niger
Comparative effect of mineral fertilizers on degraded and non degraded soils	Karabedji	Niger
Fertilizer equivalency and optimum combination of low quality organic and inorganic plant nutrients	Banizoumbou, Karabedji, Gaya	Niger
Optimum combination of phosphate rock and inorganic plant nutrients	Banizoumbou, Gaya, Karabedji, Sadore	Niger
Biological nitrogen fixation	Several sites	Niger, Uganda
Corral experiment (demonstration)	Sadore	Niger
Conservation agriculture trials	8 sites in Africa	Kenya, Ghana, Burkina Faso
Rock phosphate	10 sites	Burkina Faso, Niger, Senegal
Water and nutrient interactions	5 sites	Mali, Niger, Ghana, Burkina Faso, Zimbabwe, Kenya
Fertilizar microdose	Several sites	Burkina Faso, Níger and Senegal

MIS Network

Members of MIS consortium

During 2005 the MIS Consortium continued strengthening the capacity of its members to improve N and P fertilizer recommendations for maize-based systems using the Nutrient expert System (NuMaSS). Two workshops were organized. Seven researchers from Nicaragua and eight from Honduras attended the first workshop. Participants compared results generated by the software using default values with those generated in the field experiments. The second workshop was given to extension agents from eight NGOs in Honduras willing to compare NuMaSS fertilizer recommendations with those currently used by farmers in different regions of Honduras.

A recent agreement between AridNet and MIS consortium allowed MIS partners to get familiar with the Dahlem Conceptual framework for degradation/desertification processes. A workshop was carried out in the Lempira region in Honduras with the participation of 17 researchers from Honduras, Nicaragua, Mexico, Colombia and US. The National Science Foundation of USA financed the meeting. Participants visited two field sites (degraded and improved) and validated the nine assertions proposed by the Dahlem Framework to describe degradation and reclamation processes.

Farmers' capacities enhanced through field trips and courses on Conservation Agriculture

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Ex- ante evaluation of land use alternatives had demonstrated that conservation agriculture is an SLM alternative for improving environmental services and rural livelihoods. Based on Fuquene (Colombia) experience, the special project "Payment for Environmental Services" of the WFCP is promoting a capacity building strategy for enhancing other pilot sites farmers' capacities in conservation agriculture. The strategy has started with training courses held in the conservation agriculture pilot site (Fuquene) and subsequent courses held directly at the extrapolation sites. The participants of the courses were selected according to their previous commitment to apply the learned practices in their own farms. The project, through the extension partners (GTZ-EPC), will provide continuous technical assistance for a year in order to ensure that the technology is properly applied during planting of green manures and commercial crops.

Four extension courses were conducted:

- Conservation Agriculture for Jequetepeque watershed (Cajamarca, Peru) farmers held in Zipaquira (Colombia).
- Conservation Agriculture for Jequetepeque watershed (Cajamarca, Peru) farmers held in Chilete (Peru).
- Conservation Agriculture for Ambato watershed (Peru) farmers held in Zipaquira (Colombia).
- Conservation Agriculture for Ambato watershed (Cajamarca, Peru) farmers held in Patate Canton (Ecuador).

Output target 2006

➢ ***At least five capacity building courses on below-ground biodiversity (BGBD) held at the global level and more at participating country level***

Completed work

During 2005 two international training courses were organized by the GEF-funded BGBD project. One training course was on the ecology and taxonomy of termites and ants.

The termites training course covered several topics on termites and ants. Topics covered included termite and ants' biology, taxonomies and functional groups with the facilitators distributing literature on the ecology of termites and ants, their evolution, assemblages and distribution in forests and other ecosystems, field sampling methods, sample preservation, identification and classification among others. The feeding characteristics, gut content and humification of the feeding substrate were also covered providing characteristics of the feeding groups based on order of humification of the feeding substrate. Discussions were also held between the countries on minimum datasets that would be common to all the countries.

The Workshop was held in the National Museums of Kenya, which provided a well appointed laboratory, with all necessary equipment and daytime catering. Five countries, Kenya, Uganda, Cote d'Ivoire, India and Indonesia were represented directly and a Powerpoint presentation of the Mexican experience sent over and shared by the rest of the participants. Mexico and Brazil had in the previous year held similar training in Brazil. During the training session, published Taxonomic Keys were requested by the participating countries and the following keys supplied: (i) Detailed Key to Termite Genera and Species in Borneo and SE Asia (Thapa, 1981), (ii) Main Key to Termite Genera of SE Asia (Tho, 1992), Detailed Key to Genera and Species of Soldierless African Tremites (Sands, 1972), Detailed Key to Gerea and Species of African Termites by the Worker Caste (Sands, 1998), Most Recent Review Volume on termite Biology, Main Key to Ant Genera Worldwide (Bolton, 1994), Taxonomic Synopsis of the Formicidae (Bolton, 2003), Standard Method for Sampling of Ants (Agosti et al., 2000) and Most Recent Review Volume on Ant Biology (Holdobler and Wilson, 1990). The training course was organized by the Global Coordinating Office of the BGBD project in conjunction with the Kenya BGBD Team. The training was facilitated by Professor David Bignell (Termites), and Dr. Gary Alpert (Ants). A total of 18 participants attended the training course (Table 27).

The second training course was on Arbuscular Mycorrhizal Fungi (AMF) and Ectomycorrhiza (ecology, taxonomy and methods of inventory). The training course was conducted in Bangalore, India, again with participants form each of the BGBD countries. In total 20 persons participated, including the resource persons.

In earlier years training course were conducted on the ecology and taxonomy of earthworms, on nematodes and a training course on molecular techniques for BGBD, which brings the total to 5 and by which the target has been met.

Table 27. List of participants for the Termites and Ants Taxonomy and Identification Training in Nairobi.

Name	Institution	Country	Name	Institution	Country
Prof. David E. Bignell	Queen Mary University of London	United Kingdom	Mr. Shaban Okurut	Makerere University	Uganda
Dr. Gary Alpert	Havard University	United States of America	Mr. Rajab Ogogol	Makerere University	Uganda
Dr. Souleymanne Konate	Université d'Abobo - Adjamé	Côte d'Ivoire	Dr. Anne Akol	Makerere University	Uganda
Mr. Mouhamadoue Kone	Université d'Abobo - Adjamé	Côte d'Ivoire	Mr. Allan Lugoolobi	Makerere University	Uganda
Mr. Sylvain Crolaud TRA-Bi	Université d'Abobo - Adjamé	Côte d'Ivoire	Dr. Christine Bakuneeta	Makerere University	Uganda
Mr. H. Guruprasad	University of Agricultural Sciences	India	Mr. Daniel Karanja	National Museums of Kenya	Kenya
Dr. F.X. Susilo	Universitas Lampung	Indonesia	Ms. Martha Sila	University of Nairobi	Kenya
Mr. Fredrick Ayuke.	Methodist University, Meru	Kenya	Mr. Reuben Mwakoli	National Museum of Kenya	Kenya
Ms. Mary Lucy Oronje	University of Nairobi	Kenya	Mr. Joseph Mugambi	National Museums of Kenya	Kenya

The AMF training course included a review of the mandatory and optional methods for studying AMF for the BGBD project, the taxonomy of AMF based on morphology, new terminologies used in the taxonomy of AM fungi and the importance of the number of layers in the spore wall and germinal walls, and the pregermination structures. The theories were followed by practicals where the participants had the opportunity to microscopically observe the spore structures as and when the same was projected on a screen and explained. The participants were allowed to take some of the slides for their future reference. Molecular approaches for the identification of AMF were also taught (Table 28). Protocols for the extraction of DNA and amplification of 18S rRNA and ITS region by PCR were presented. Gel electrophoresis of DNA was also presented. The theories were followed by practicals in which DNA from the spores of 4 AMF. A detailed account on the taxonomy of ectomycorrhizal fungi was also presented. Manuals and Powerpoint presentations were given to the participants for use in the own countries. The training course was organized by the Global Coordinating Office of the BGBD project in conjunction with the Indian BGBD Team. The training was facilitated by Professor David Joseph Bagyraj, Dr. Sidney Sturmer, Dr. G.S. Prasad, Prof. K. Natarajan and Dr. Joyce Jefwa.

Table 28. List of participants for the Mycorrhizal Fungi Training in India

Name	Institution	Country	Name	Institution	Country
Dr. Sidney Liz Stummer	Univesidada Regiona de Blumenau (FURB)	Brazil	Dr. Gerad Mutumba	Makerre University	Uganda
Prof. Joseph Bagyaraj	University of Agricultural Sciences	India	Ms. Susan Serani	Makerere University	Uganda
Dr. Adolphe Zeze	Institut National Polytechnique Laboratoire de Microbiologie de sols	Côte d'Ivoire	Mr. Henry Kiryose	Makerere University	Uganda
Mr. Zabouo Armand	Institut National Polytechnique	Côte d'Ivoire	Dr. Joyce Mnyazi Jefwa	National Museums of Kenya	Kenya
Dr. T. Prasad	University of Agricultural Sciences	India	Mr. Peter M. Wachira	University of Nairobi	Kenya
Dr. G.S. Prasad	University of Agricultural Sciences	India	Dr. Dora Trejo Aguilar	Instituto de Ecologia A.C.	Mexico
Dr. Maria Viva Rini	Universitas Lampung	Indonesia	Dr. Lucia Varela Fregoso	Instituto de Ecologia A.C.	Mexico
Mr. Joko Prasetyo	Universitas Lampung	Indonesia	Dr. Javier Alvarez	Instituto de Ecologia A.C.	Mexico

Apart from the training courses, the BGBD project held its annual meeting in April, 2005 in Manaus, Brazil. A total of 71 participants participated in the annual meeting. Participants were drawn from Brazil, Cote d'Ivoire, India, Indonesia, Kenya, Mexico, and Uganda as the core participants. Other participants who were mainly the Technical Advisors and Project Advisory Committee members were drawn from the United Kingdom, United States of America, France, and from Colombia, the location of CIAT headquarters. Also participating during the annual meeting were Professor Eric Smaling and Professor Maatete Bekunda who had been contracted by UNEP to carry out the mid-term review of the BGBD project.

The annual meeting presented a good opportunity where the participating countries presented the results of their work and were able to compare results and experience between countries through oral transactions and interactions. A total of 71 papers were presented in six technical sessions. The technical sessions included: (i) Benchmark area description and socio-economic characterization, (ii) Results of the inventory of macro-fauna, (iii) Inventory of nematodes and mesofauna, (iv) Inventory of legume nodulating bacteria and arbuscular mycorrhizal fungi (AMF) (v) Inventory of pathogenic and antagonistic fungi and insect pests and (vi) Standard methods for the inventory of BGBD. In addition to these there were Task Force reports on Ecosystem Services, Land Use Intensity and Economic Valuation of BGBD. There was also a report of the technical committee and four planning sessions. The output from the annual meeting are two reports one on the Standard Methods for the Assessment of Soil Biodiversity in the

Context of Land Use Practices and the other is the Technical Report of the Project Annual Meeting, April, 2005 all existing as separate volumes of the CSM-BGBD reports. Following is a list of papers presented during the annual meeting.

Benchmark area descriptions and socio-economic characterization

1. Characterization of Benchmark sites in India
   Balakrishna Gowda, U.M. Chandrashekara, M.P. Sujatha and R.K. Maikhuri
2. Benchmark description: Lampung, Indonesia
   Afandi, M. Utomo and D. Mizwar
   Land use & Socio-economic Characteristics of the Sumberjaya BA
   Rusdi Evizal, S. Bududarsono and H. Ismono
3. Los Tuxtlas Benchmark area description and sampling approach
   José Antonio Garcia, Simoneta Negrete-Yankelevitch
   Socio-economic characterization of three communities of the Los Tuxtlas area
   Isabelle Barois
4. Characterisatin of land use types in the Mabira Forest ecosystem, Uganda
   G. Lamtoo and M. J. N. Okwakol
   Socio-economic characteristics and indicators of below-ground biodiversity in Mabira Forest ecosystem, Uganda
   E. Balirwa, B. Mugonola and G. Byandala
5. Land use land cover mapping using high resolution images of The Upper Solimões River, Benjamin Constant Municipality, Am, Brazil
   Elaine Cristina Cardoso Fidalgo (1), Maurício Rizzato Coelho (1), Fátima M. S. Moreira (2), Fabiano de Oliveira Araújo (1), Humberto Gonçalves dos Santos (1), Maria de Lourdes Mendonça S. Brefin (1).
6. The Physical Environment With Emphasis in Upland Soils of The Upper Solimões River, Benjamin Constant Municipality, Am, Brazil.
   Maurício Rizzato Coelho, Elaine Cristina Fidalgo, Fabiano of Oliveira Araújo, Humberto Gonçalves dos Santos, Maria of Lourdes Mendonça Santos Brefin EMBRAPA Solos, RJ.
7. Flora survey in Upland Soils Of The Upper Solimões River, Benjamin Constant Municipality, Am, Brazil
   Hiroshi Noda(1), Ieda Amaral(1), Ayrton Urizzi(2), Danilo Fernades da Silva Filho(1), Francisco Manoares Machado(1), Jucélia Oliveira Vidal. (1)
8. Land-use mapping and typology in Oumé benchmark site (Centre-West Côte d’Ivoire)
   N’DoumE C1, GnessougoU N1, Tondoh J E2, TANO Y3.
9. Demographic and socio-economical characterisation of the Oumé benchmark area (Centre-West Côte-d’Ivoire)
   Ogni K. B1, Ibo J2, Agnissan A A1
10. Morphological and physical characteristics of soils along a gradient of land use intensity in Center-West Côte-d’Ivoire
    Angui P.K.T.11 Tie B.T2., Tamia J.A1., Assie K. H1., Danho D. M1
11. Impact of human activities on floral diversity in the Oumé Region (Centre-West Côte d’Ivoire)
    N'Guessan K. E; Ake-assi L; Kouassi K. E; Assi Y. J; Sagne C.
12. Land use and biophysical characterization of below-ground biodiversity (bgbd) benchmark site in kenya
    E.M. Muya, N. Karanja, H.Roimen, and B. Mutosotso

Result of the inventory of soil macro fauna

13. Termite Diversity in a Range of Land Use Types in Sumberjaya
    F.X. Susilo and F.K. Aeny

14. Ant Diversity in a Range of Land Use Types in Sumberjaya
    F.X. Susilo and Hazairin
15. Beetle Diversity in a Range of Land Use Types in Sumberjaya
    F.X. Susilo, A.M. Hariri, Indriyati, and L. Wibowo
16. Earthworm Diversity in a Range of Land Use Types in Sumberjaya
    W.S. Dewi and Sri Murwani
17. Biodiversity of the Macrofauna in Santa Marta los Tuxtlas , Veracruz México.
    Isabelle Barois, Martín de los Santos, Simoneta Negrete-Yankelevich and Jose Antonio Garcia
18. Inventory of Earthworms in the Los Tuxtlas benchmark area.
    José Antonio Garcia
19. Ants and termites abundance and diversit in three location within lox Tuxtlas BA Simoneta Negrete-Yankelevitch
20. Coleoptera in Santa Marta Los Tuxtlas, Veracruz, Mexico
    Miguel A. Morón & Roberto Arce (Isabelle Barois)
21. Effects of land use change on the diversity and abundance of earthworms in a tropical high forest ecosystem in Uganda
    Nkwiine C, Okwakol M J N, Rwakaikara M S and Akol A
22. Effects of land use change on the diversity and abundance of soil macrofauna (termites, ants and beetles) in a tropical high forest ecosystem in Uganda
    Alemu S O, Akol A and Okwakol M J N
23. The abundance and diversity of earthworms and termites in the BGBD benchmark sites.
    G.H.N.Nyamasyo; M. Kibberenge and Fred Ayuke.
24. Diversity of earthworm along a gradient of agricultural landscape in Centre-West Region of Côte d'Ivoire
    Tondoh E. J1, Monin L 1, Tiho S2, CSUZDI C3
25. Diversity of termites and ants along a gradient of land-use in a tropical forest margins (Oumé, Côte d'Ivoire)
    Konate S.1; Tra-bi S.C.2; Adja A.N2; Katia S.C.1; Kolo Y.1 & Tano Y.2
26. Composition Of Soil Macro-Invertebrates Communities In Different Land Use Systems In Alto Solimões, Brazil
    Sandra Celia Tapia-Coral & José Wellington Morais
27. Community structure of ants in different land use systems in the upper Solimões River – AM
    Ronald Zanetti, Nívia Dias, Mônica Silva Santos, Márcia Lídia Gomide, Jacques Delabie
28. Scarabaeidae (Insecta: Coleoptera) community structure in different soil use systems in the the upper Solimões River – AM.
    Silva, P.H.; Louzada, J.N.C.; Shiffler, G
29. Diversity of Termites in diverse Land Use Systems in Benjamin Constant Municipality, AM, Brazil.
    Agno Accioly and Reginaldo Constantino.
30. Inventory of macrofauna in different land use systems in the Nilgiri and Nanda Devi Biosphere Reserve in India
    Radha D. Kale, N.G. Kumar, B.K. Senapati, R.V. Varma and R.K. Maikhuri

Results of the nematodes and meso-fauna inventory

31. Collembola Diversity in a Range of Land Use Types in Sumberjaya
    Cahyo Rahmadi and I Gede Swibawa
32. Nematode Diversity in a Range of Land Use Types in Sumberjaya
    I Gede Swibawa (F.X. Susilo)
33. Nematodes in Los Tuxtlas Mexico
    Pilar Rodrigeuz Gusmán
34. Sampling of the mesofauna of Sierra de Santa Marta in Los Tuxtlas Veracruz, México
    Isabelle Barois, Martín de los Santos, Antonio Angeles, José Antonio García and Patricia Rojas.

35. Effects of land use change on the diversity and abundance of soil nematodes in Mabira forest ecosystem, Uganda
    Namganda J, Bafakuzara D and Nabulya G
36. Effects of land use change on the diversity and abundance of soil Mesofauna in Mabira forest ecosystem, Uganda
    Akol A, Alemu S O and Lamtoo G
37. Inventory of mesofauna in different land use systems in the Nilgiri and Nanda Devi Biosphere Reserve in India
    R.V. Varma, B.K. Senapati, N.G. Kumar and R.K. Maikhuri
38. Response of the nematode communities to different land-use systems in the upper solimões river basin in northern brazil.
    Cares2, J. E. & Andrade2,, E. P.
39. Density and diversity of soil meso-invertebrates in different land use systems, in Alto Solimões, Amazonas, Brazil.
    José Wellington de Morais & Sandra Celia Tapia-Coral
40. Effects of various land uses on nematode communities in Côte d'Ivoire
41. Collembola Diversity in a Range of Land Use Types in Sumberjaya
    Cahyo Rahmadi and I Gede Swibawa
42. Nematode Diversity in a Range of Land Use Types in Sumberjaya
    I Gede Swibawa (F.X. Susilo)
43. Nematodes in Los Tuxtlas
    Pilar Rodrigeuz Gusmán
44. Sampling of the mesofauna of Sierra de Santa Marta in Los Tuxtlas Veracruz, México
    Isabelle Barois, Martín de los Santos, Antonio Angeles, José Antonio García and Patricia Rojas.
45. Effects of land use change on the diversity and abundance of soil nematodes in Mabira forest ecosystem, Uganda
    Namganda J, Bafakuzara D and Nabulya G
46. Effects of land use change on the diversity and abundance of soil Mesofauna in Mabira forest ecosystem, Uganda
    Akol A, Alemu S O and Lamtoo G
47. Inventory of mesofauna in different land use systems in the Nilgiri and Nanda Devi Biosphere Reserve in India
    R.V. Varma, B.K. Senapati, N.G. Kumar and R.K. Maikhuri
48. Response of the nematode communities to different land-use systems in the upper solimões river basin in northern brazil.
    Cares, J. E. & Andrade, E. P.
49. Density and diversity of soil meso-invertebrates in different land use systems, in Alto Solimões, Amazonas, Brazil.
    José Wellington de Morais & Sandra Celia Tapia-Coral
50. Effects of various land uses on nematode communities in Côte d'Ivoire
    Gnonhouri G. P1, Nandjui J2, Adiko A1

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Results of the inventory of leguminosae nodulating bacteria, arbuscular mycorrhizal fungi (and ectomycorrhiza).

51. Leguminosae nodulating bacteria in four land uses from Santa Marta Los Tuxtlas.
    Esperanza Martínez, Lourdes Lloret , Pablo Vinuesa (Dora Trejo)
52. Land Use and Diversity of Arbuscular Mycorrhizal Fungi in Mexican tropical ecosystems
    Varela, L., D. Trejo, F.J. Álvarez, I, Barois, E. Amora-Lazcano, P. Guadarrama, L. Lara, D. Olivera, I. Sánchez-Gallén, W. Sangabriel, R. Zulueta.
53. LNB Diversity in a Range of Land Use Types in Sumberjaya
    R.D.M. Simanungkalit and Agus Karyanto

AMF Diversity in a Range of Land Use Types in Sumberjaya
Yadi Setiadi, Noor Faiqoh, and Agus Karyanto

54. Charaterization of Phaseolus vulgaris, Glycine max and Macroticlum atrapurpereum nodule bacteria under different land use types in Mabira forest ecosystem, Uganda
Rwakaikara M S, Zawedde J and Kizza C L
55. Impact of land use change on the diversity and abundance of Mycorrhiza in Mabira forest ecosystem, Uganda
Mutumba G, Serani S and Lamtoo G
56. Morphological diversity of AM fungi isolated from the TENE area in Center-West Côte d'Ivoire
ZEZE Adolphe, Ouattara Brahima and Zabouo Armand
57. Investigation of rhizobia ressources in the TENE region in Center-West Côte d'Ivoire
Koné Kinanpara, ZEZE Adolphe, Kimou Akomian
58. Assessment of diversity of legume nodulating bacteria (LNB) in Nilgiri and Nandadevi Biospheres of India A. N. Balakrishna, M. Balasundaran2, R. K. Singh3, R.K. Maikhuri4, S. Shanker1, Devyani Sen3, S. Binisha2 & A. Chandra4
59. Diversity of AM fungi across a gradient of land uses in Western Ghats and Nanda Devi biosphere
A.N. Balakrishna, R.K. Maikhuri and K.V. Sankaran
60. Density and diversity of associative diazotrophic bacteria in soils under diverse land use systems in Amazonia
61. Fátima M. S. Moreira,: Rafaela Nóbrega, Adriana Lima, Alexandre Barberi, Krisle da Silva, Ligiane Florentino
62. Diversity of leguminosae nodulating bacteria from three different land use systems in Brazilian Western Amazon
63. Ederson da Conceição Jesus(1), Ligiane Aparecida Florentino(1), Maria Isabel Dantas Rodrigues(1), Marcelo Silva de Oliveira(2) e Fátima Maria de Souza Moreira(1)
64. Diversity of Leguminosae nodulating bacteria in diverse Land use systems in the upper Solimões River Basin, Benjamin Constant Municipality, AM- Brazil by using three trap species.
65. Fátima M. S.Moreira(1), Adriana S.Lima(2), Alexandre Barberi(2 Ligiane Florentino(3), Paulo Avelar Ferreira(3), Michele Aparecida da Silva(3), Marlene A de Souza(4), Marcelo de Oliveira(5)
66. Diversity and community structure of arbuscular mycorrhizal fungi in several land use systems in the Amazon.
Sidney L. Stürmer(1), José O. Siqueira (2), Carlos R. Grippa (1), Patricia Alves(1), Glaucia Alves Silva(1).
67. Abundance and growth characteristics of legume nodulating bacteria in Embu and Taita benchmark sites of Kenya
David W. Odee1*, E. Makatiani1, Nancy Karanja2 and James Kahindi3

Results of the inventory on pathogenic and antagonistic fungi and insect pests

68. Inventory and diversity of soil-borne plant pathogenic fungi in the biosphere reserve of los Tuxtlas, Veracruz, Mexico.
María del Pilar Rodríguez-Guzmán and Grisel Negrete-Fernández.
69. EPF and PPF Diversity in a Range of Land Use Types in Sumberjaya
Darmono Taniwiryono and Titik Nur Aeny
SDF Diversity in a Range of Land Use Types in Sumberjaya
Iswandi Anas, Titik Nur Aeny, and Joko Prasetyo (F.X. Susilo)
70. Relative abundance of pathogens in different land use types in the Mabira forest ecosystem, Uganda
Akol A and Alemu S O
71. The diversity and abundance of entomopathogenic fungi in relation to land use in Mabira forest ecosystem, Uganda
Serani S and Akol A

72. Monitoring diversity of microfungi in soils under different conditions of land-use
Ludwig H. Pfenning, Lucas M. de Abreu, Mirian Salgado, Larissa Gomes da Silva, Janine Mendes de Oliveira, Anderson R. Almeida, Ricardo T.G. Pereira
73. Inventory of entomopathogenic nematodes and fungi on soil samples.
Alcides Moino Junior, Ricardo Souza Cavalcanti, MSc, Vanessa Andaló,
74. Diversity of fruit flies (Diptera: Tephritidae) and potencial impacts on traditional agroforestry systems in the upper Solimões River- AM.:
Dr. Neliton Marques, Frederico Vasconcelos, Alexandra Priscila Tregue
75. Characterization of soil fungi in different agro-ecological units in Center-West Côte-d'Ivoire
Abo K., Diallo A.H.., Koffi N. B. C., Ganiyu K., Babacauh, K.D., and Agneroh A. T.
76. Characterization of saprophytic fungi in the Nilgiri Biosphere Reserve in India
A.N. Balakrishna
77. Land use systems and distribution of Trichoderma species in Embu
Sheila Okoth

Review of standard methods

78. Standard methods for the inventory of earthworms
Jérôme Tondoh
79. Standard method for the inventory of ants and termites
Souleymane Konate
80. Methods of Below-ground Mesofauna Inventory
Agus Karyanto and F.X. Susilo
81. Methodology for soil nematode diversity evaluation
Huang, S. P. (in memoriam), Cares, J. E. & Andrade, E. P.
82. Standard methods for the inventory of LNB
Fatima Moreira
83. Standard methods for endo- and ecto-mycorrhizal fungi
A.N. Balakrishna
84. Standard methods for the inventory of phyto-pathogenic and antagonistic fungi
Sheila Okoth
85. Standard methods for the inventory of fruit flies
Neliton Marques

Ecosystem services and soil quality indicators

86. Introduction to the session Tasks of the ESERV task force and summary of the discussions on methods for ecosystem service,
Edmundo Barrios.
87. GBD and farmer appreciation of Ecosystem Services
Jo Anderson
88. Carbon stocks under different land uses in Oumé Region (Center-West Côte d'Ivoire)
Yao K.M1, Abbadie L2, Konate S1, Benest D2.
89. Assessing soil morphology: a simple and robust method to evaluate the role of soil ecosystem engineers and other soil structuring processes
Elena Velasquez and Patrick Lavelle
90. Soil engineering by Arbuscular Mycorrhizal Fungi
E. Barrios and M. Rillig
91. Qualitative distribution of soil agregates
Maria da Glória B. F.Mesquista, Mauricio Coelho, Fernanda Perechi, Maria Tereza Carvalho (Fatima Moreira)

92. Evaluation of soil fertility in different Land Use Systems in upland soils of The upper Solimões River, Benjamin Constant Municipality, Am, Brazil
    Sonia Alfaia, Fernanda Villani, Katell Uguen, Acácia Neves, José Edvaldo Chaves,
93. Integrated control of subterranean pests in South America
    Andreas Gaigl

Analyses of BGBD at landscape level and land use intensity

94. Land Use Intensity of CSM-BGBD Sumberjaya Window, Lampung Benchmark, Indonesia Rusdi Evizal1, Suseno Budidarsono2, F. Erry Prasmatiwi3
95. Operationalisation of the Land Use Intensity Index: the Mexican case
    Simoneta Negrete-Yankelevich and Tajín Fuentes-Pangtay
96. Proposal of a spatial analysis of BGBD project data: up scaling from point to global scale in three steps, Simoneta Negrete-Yankelevich
97. Spatial analyses and scale aspect to inventory of BGBD
    Richard Coe

Economic valuation case study

98. Economic evaluation of production systems in the OUME Region (North-West Côte d'Ivoire)
    Barry M.B. and Kouadio E.
99. Conservation and breeding in situ: contributing to the preservation of traditional knowledge/ Social economic aspects of The Upper Solimões River, Benjamin Constant Municipality, Am, Brazil
    H.Noda and S.Noda

Project Phase II Planning Session

100. The BGBD project's data base; implementation by the Global Coordinating Office and Participating Country Programmes
     P. Okoth
101. Portal BiosBrasil, and online training course software R.
     Fatima Moreira
102. Framework for development of proposals for the second phase of the project
     Jeroen Huising
103. Plans for the second phase of the Mexican BGBD programme
     Isabelle Barois
104. Plans for the second phase of the Brazilian BGBD programme
     Fatima Moreira
105. Plans for the second phase of the Cote d'Ivoire BGBD programme
     Jerome Tondoh
106. Plans for the second phase of the Indonesian BGBD programme
     Felix Susilo
107. Plans for the second phase of the Indian BGBD programme
     K.G. Saxena
108. Plans for the second phase of the Kenya BGBD programme
     J.H.P. Kahindi, N. Karanja, E. Muya, S. Okoth, J. Kimenju, B. Mutsoso, J. Jefwa, D. Odee, and J. Ramisch
109. Plans for the second phase of the Uganda BGBD programme
     Mary Okwakol
110. Data sharing and intellectual property rights
     Peter Okoth

To strengthen the CSM-BGBD project network and linkages the project continues to maintain a website and mailing lists to all its members. The project also has an FTP transfer mechanism for documents that are too large to thread through the email. This has made it easy to exchange documents and reports between the global coordinating office and the country projects. The project also maintains a server repository with ICRAF as a stop gap measure against machine breakdown or loss. The BGBD project partners with about eighty institutions spread across the countries and works with well over 150 scientists. The Table 29 below shows the categories of partnerships that the BGBD project has.

Table 29. Categories of partnerships within the BGBD project.

Programme	**Year start -ed**	**TOTAL**	**Extent of partnerships**								**Govern-ance structure**	**Coordin-ation mechanism**
			International (including regional)				**National and local**					
			IARCs	Uni-versi-ties*	NGOs	OTHER**	NARs	Universities*	NGOs	OTHER		
BGBD	2002	79	7	7	0	0	37	21	5	2	Yes	Yes

Output target 2007

- ***Strategy for building capacity for SLM is developed with partners***

Work in progress

Social capital and adoption of soil fertility management technologies in Uganda
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A range of soil fertility management technologies have been promoted through research and extension to ensure adequate replenishment of soil fertility and increase crop production. However, despite these many efforts, the rates of adoption remain low. Social capital is crucial for adoption of soil fertility management technologies, as it provides social networks, relationships and linkages that enable people to co-operate, co-ordinate, access and share information and resources, and act collectively. This was investigated through a study conducted with 106 female and male farmers in eastern Uganda, looking at the levels and dimensions of social capital and their influence on adoption of soil fertility management technologies. Results show that although still limited, adoption rates of legume cover crops were higher for group members compared to farmers who do not belong to a group. Farmer' groups had higher levels of social capital, as measured by, co-operation, extent of trust, information sharing and participation in collective activities. On the other hand, indicators of weak social capital, such as selfishness, individualism and conflict were found to be higher in the general community than in farmer' groups. The frequency of visits by extension workers, extent of cooperation and information sharing positively correlated with adoption of legume cover crops whereas the extent of conflict and education was negatively related to adoption. There was higher adoption of technologies by farmers who were in a group, implying that social capital influences adoption of technologies. The paper argues that strengthening local organizations through farmer groups would increase adoption of soil fertility management technologies.

Sustainable promotion and development of soybeans in the farming systems of Kenya: The working of strategic alliances
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Soybean was introduced in the farming systems of Kenya many decades ago. However, the crop has remained a minor crop despite its great potentials for improving household food and nutrition security (through quality food supply), household cash income (through the sales of soybean and soybean products), household health (through the provision of high quality protein-rich food), and soil fertility improvement (through its atmospheric nitrogen-fixing ability). Literature indicates that low yield, lack of knowledge on its utilization, and lack of market are among the key factors that have contributed to lack of widespread adoption of soybeans in the farming systems of Kenya. A recent effort based on improved dual-purpose promiscuous soybeans varieties sourced from IITA, Ibadan, Nigeria has been commenced by TSBF-CIAT and aims at solving the different problems that forestalled the take-off of this crop in the past by engendering strategic alliances of all the stakeholders that can contribute in one way or another in sustainable promotion and development of soybean in the farming systems of Kenya.

The objectives of this study are: (1) to understand the missing links that prevented widespread adoption and production of soybean in the farming systems of Kenya despite great efforts to promote the crop in the past, (2) to search for, contact, discuss with, and prioritize among different stakeholders or partners that can contribute towards alleviating missing links that have prevented widespread adoption and production of soybean in the farming systems of Kenya, (3) to develop the strategies for all the partners in the strategic alliance to work on defined and complementary roles in the new initiative for the promotion and development of soybean in Kenya, and (4) make recommendations on plausible strategic alliances for future development and promotion of a crop or livestock sub-sector in Kenya.

This study is being carried out in Nairobi. Literature review and interactions with various stakeholders (individual soybean farmers; producer groups; food processing industries; livestock feed industries; supermarket operators; farm input suppliers; staff of the Ministries of Agriculture, Trade and Industry, Finance, and Planning and Economic Development; staff of the National Agricultural Research Systems including research institutes and the Universities; Key informants, etc.) were used to identify the missing links that prevented widespread adoption and production of soybean in the farming systems of Kenya despite great efforts to promote the crop in the past. Following this, some brainstorming sessions were organized and are used to list the potential partners that could be approached for their cooperation in the new initiative for sustainable development and promotion of soybeans in the farming systems of Kenya. Appointments to discuss the strategy were made with each of the listed partners and decisions taken were documented in minutes of related meetings shared with all in attendance at the meetings.

For the different functions, the following partners (see Table 30) have agreed to work with TSBF-CIAT (discussions are still going on with other partners) in the strategic alliance for the development and promotion of soybean in the farming systems.

Table 30. Partners to TSBF-CIAT in the strategic alliance for the development and promotion of soybeans in the farming systems of Kenya.

Function	Partners	Type of Organization
Research to develop technologies	Kenya Agricultural Research Institute, Kenyatta University, Jomo Kenyetta University of Agriculture	Research institutes and Universities
Producer groups	Ebubala Self-Help Group, Tushiauriane Self Help Group, Nabongo Panga Self-Help Group, Jitolee Women Group, Etako Women Group, Bushe Women Group, Shishebu Women Group, Masaa Men and Women Group, Eluche Mwangaza Community Development Organization,	Farmer organization
Inorganic fertilizer supply	FIPS-Africa	Private business organizattion
Micro-credit supply	K-Rep Development Agency	Micro-credit institution
Seed supply	Western Seed Company, Kenya Seed Company	Private and Public Companies
Seed/grains bank development	SACRED-Africa	NGO
Food processing industries for the marketing of output	Bidco, NUTRO EPZ	Private companies
Transportation of output	Farmers' Own Trading Company, Kenya Agricultural Commodity Exchange (KACE)	NGO
Information development and dissemination	AfriAfya	NGO
Scaling out and scaling up	Ministry of Agriculture, Ministry of Trade and Industry; Ministry of Finance; Ministry of Planning and Economic Development; Poverty Eradication Commission	Public institutions and Commission
Research funding	The Rockefeller Foundation	Donor organization

Facilitation of improved decision making of farmers, extension agents and policy makers for improved land management in crop-livestock systems of Ethiopian Highlands

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Most of the land in Ethiopian highlands that was classified as very suitable for cultivation is already under cultivation (FAO, 1986). Farmers are attempting to intensify their agricultural production by utilising marginal lands and converting communal grazing lands to arable land but with limited integration of improved innovations. In these highlands systems where land degradation is the major threatening factor, the resource base in terms of nutrients, water, organic matter and soil are deteriorating causing a decline in agricultural productivity and environmental stress (Amede et al., 2001). Moreover, the extensive livestock management that has been traditionally practiced over years became an apparent challenge not only for technology integration, like agroforestry systems, but also to capture and concentrate nutrients in the form of quality manures.

A considerable amount of information could be available in the various project sites on crop and livestock enterprises, yet predictions and recommendation are difficult due to the variable nature of biological and socio-economic variables and the trade-offs between production and management of resources and inputs. Linking these data with models that simulate livestock productivity, increased marketable enterprises, intensify nutrient cycling and improve market response could provide a means of making initial recommendations for promoting farmers' livelihoods. Incorporation of market needs, farmer production objectives, risk assessment and farmer decision making into this approach will allow the development of decision making tools towards more accurate targeting that will improve the management of crop-livestock systems, improved rural livelihoods and increased household food security. Moreover, resource-poor farmers, particularly those far away from markets, face difficult decisions over the use of scarce resources of land, labour, nutrients and water in their respective production systems. Often the decisions taken on the allocation of resources are taken without an assessment or appreciation of the impact of the traditional wisdom on financial gains and food security with out considering its potential effect on other system components of feed production, soil fertility management, soil erosion and related issues.

This work is attempting to identify, synthesize, simplify and validate tools, methods and approaches in improved land management, with emphasis on integrated soil fertility management by considering biophysical and socio-economic driving forces behind farmers' decision making. This project will utilise a combination of trade-off analysis, partial budgeting of new technologies and farmer knowledge to identify, introduce, validate and disseminate new crop-livestock interventions. It has been developed as response to the invitation of the ILRI-CIDA (IPMS project) to provide tools and methods to improve the decision making of farmers, communities and policy maker operating in IPMS pilot sites and beyond. We anticipate the use of decision support tools will the serve the extension system for achieving high household income, food security and improved system integration. It has started in late 2005 and will be implemented in 2 districts of southern Ethiopia, where about 100,000 people are farming in each district, with further potential to scale-up the approach to other 10 districts in 2007 and beyond.

After screening proven methods and approaches together with partners we will integrate and transfer our experience to the extension system of Ethiopia in 2006 and beyond, particularly in integrated land management.

Output target 2007

➢ ***At least three capacity building courses on ISFM held by AfNet , MIS and CONDESAN***

Work in progress

Use of the Nutrient Management Expert System NuMaSS to improve management of nitrogen in maize-based systems in hillsides of Honduras and Nicaragua

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In 2004 partners of the MIS Consortium and researchers from the CRSP-USAID Consortium initiated 2-year trials in Honduras and Nicaragua to acquire corn cultivar and soil coefficients for developing improved N fertilizer recommendations using the Nutrient Management Support System (NuMaSS) software. Table 31 shows the main chemical properties of several sites included in the experiment. The amount of fertilizer N recommended by NuMaSS is the balance between the total amount of N needed by the crop and the N acquired from the soil, plant residues and cover crops, with a subsequent adjustment for the fertilizer N use efficiency by the crop. Although the software provides default values derived from reviews of existing publications for many of these plant factors it is possible to generate specific N recommendations the prevailing cultivars and soils cropped in the region.

Forty to seventy days prior to planting corn in 2004, three replicates with ten 4 m x 4 m plots were established at four locations in Honduras: Catacamas, La Ceiba, Talgua, and Yorito. Three different varieties of legume cover crops were planted in three plots within each replicate. Prior to planting corn, cover crops were cut by hand and residues uniformly distributed in their respective plots. Corn was planted in all plots using a spacing of 80 cm between rows and 40 cm within rows. A total of ten treatments were applied in each block: three cover crop treatments and seven urea-N treatments. Urea-N was applied at rates of 0, 20, 40, 80, 120, 160 or 200 kg N ha^{-1} in a split application of two equal amounts at 25 and 40 days after corn planting. Cover crop treatments did not receive urea-N. To avoid soil P limitation, 100 kg P ha^{-1} was applied to all treatments at all locations. In areas where rainfall was insufficient corn was planted without cover crops with seven urea-N rates (0, 20, 40, 80, 120, 160 or 200 kg N ha^{-1}). Treatments were replicated in three blocks at each of these locations using the same split-application procedure described above. At each trial site, data for nutrient content of soils and plants, and stover and grain yield were collected.

Table 31.. Routine soil test data prior to fertilization and planting at some of the fertilizer N and legume cover crop trial sites in Honduras and Nicaragua.

Location		**Exchangeable**				**Al**		**Olsen-Extractable**		
	pH	**Ca**	**Mg**	**K**	**ECEC[a]**	**Sat.[b]**	**P**	**Cu**	**Mn**	**Zn**
		--------- $cmol_c$ kg^{-1} ---------				%		---------- mg kg^{-1} ----------		
Candelaria	4.8	9.7	2.2	0.3	13.2	9	17.1	3	21	0.8
Comayagua	7.1	17.7	2.4	0.3	20.4	0	32.5	4	1	2.1
Catacamas	6.8	17.2	2.7	0.9	20.8	0	23.2	4	49	4.9
San Dionisio	5.8	13.8	2.9	0.2	17.0	1	12.2	4	4	1.4
San Rafael	6.0	14.2	2.5	0.2	17.0	1	21.4	4	14	2.0

[a] Effective cation exchange capacity (Ca+Mg+K+Al).

[b] %Al saturation of ECEC.

Results obtained in the Talgua site in Catacamas, Honduras are presented in Figure 32 and are used here to demonstrate the statistical analyses performed on field and lab data, and applications of the derived values in NuMaSS recommendations for N.

In the absence of other values for grain, stover, or soil N content, the derived yield without N application may be input as the previous corn crop yield to estimate native soil N contribution (N_{soil}) to the intended corn crop. The current default value in NuMaSS for this factor is 2.5 Mg ha^{-1}, which is considerably lower than the experimental value of 5.2 Mg ha^{-1}. Using the experimental value in place of the default value would reduce the final N recommendation made by NuMaSS for the Talgua site. In addition, the maximum yield derived through this trial provides a reliable estimate of target crop yield, another value required by NuMaSS. The current default value for intended yield is 3.3 Mg ha^{-1}, less than half of the maximum yield (7.4 Mg ha^{-1}).

Grain yield in the cover crop treatments was similar or inferior to that of the zero-N treatment at the Talgua site (Figure 32). The poor fertilizer N equivalency of the legume cover crops was attributed to the limited growth period (< 30 days) for biomass production and N accumulation prior to their cutting and planting corn, as evidenced by legume aboveground dry biomass of 0.2, 2.1 and 2.6 t ha^{-1}, respectively, for *Dolichos*, *Mucuna*, and *Cannavalia.*

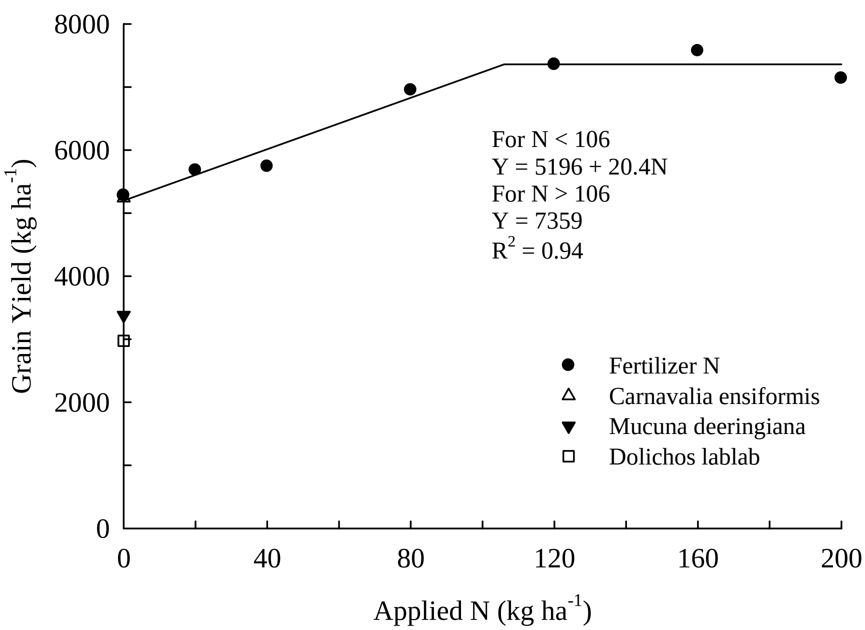

Figure 32. Corn grain yield at Talgua, Honduras as a function of fertilizer N and antecedent legume cover crops.

In the absence of a grain: stover ratio value for a given variety, NuMaSS recommends a default value of 0.84, based on an average of existing coefficients for corn in the software database. At Talgua, the quantity of total crop N uptake estimated by NuMaSS to realize an intended yield of 7.4 Mg ha^{-1}, using the default grain: stover ratio value is 128 kg ha^{-1}. When the experimental value (1.11) is used, NuMaSS estimates total crop N uptake as 116 kg ha^{-1}, less N than with the default software value.

Total N uptake (Y_r*N_{cr}) for each N fertilizer treatment was determined using the equation: [Grain dry weight * (% N grain/100)] + [stover dry weight * (% N stover/100)] = total N uptake. The quantity of native soil N uptake (N_{soil}) was represented by total N uptake when no N was applied (75 kg N ha^{-1}). The quantity of fertilizer N uptake in each treatment was derived using the equation: Total N uptake – native soil N uptake = apparent fertilizer N recovery, which assumes that N_{soil} is constant for all N fertilizer treatments. The slope of the relation between apparent fertilizer N recovery and applied fertilizer N in represents the fertilizer N use efficiency (Ef), which is estimated as 49% at the Talgua site.

Fertilizer N recommendation with cultivar- and soil-specific variables - Data regarding N content of grain and stover, native soil N, and fertilizer N recovery for a specific cultivar and soil can be applied to NuMaSS to improve local N recommendations. When compared to the yield response data in Figure 1, the N recommendation with default NuMaSS values under-estimated fertilizer N needs by 28 kg ha^{-1}, whereas use of crop and soil coefficients developed through the experiment at Talgua over-estimated fertilizer N needs by 14 kg ha^{-1}.

Conclusions: There was a 2.5-fold difference in grain: stover ratios among the predominant corn cultivars cropped in Honduras and Nicaragua. Maximum yields among 6 trial sites differed by over 5 t ha^{-1} and optimum fertilizer N rates ranged from 0 to 113 kg ha^{-1}. These differences in cultivar characteristics along with differences in yield potential and native soil N supply among the trial sites indicate that improved fertilizer N recommendations require knowledge of both the intended crop cultivar and site characteristics.

Output target 2007

- ***Books, web content and papers produced by partners in BGBD project both north and south in seven tropical countries***

Completed work

In 2005 the BGBD project produced below-ground biodiversity reviews carried out by three countries viz.: India, Indonesia and Kenya. India published a book titled "Soil Biodiversity, Ecological Processes and Landscape Management: P.S. Ramakrishnan, K.G. Saxena, M.J. Swift, K.S. Rao and R.K. Maikhuri (Editors); ISBN 81-204-1617-1 published by Oxford and IBH Publishing Co Pvt. Ltd., New Delhi, India.

Indonesia also published a book titled " Conservation and Sustainable of Below-Ground Biodiversity in Indonesia: F.X. Susilo, Abdul Gafur, Muhajir Utomo, Rusdi Evizal, Sri Murwani and I. gede Swibawa (Editors); ISBN 979-8287-69-X copyright by Universitas Lampung, Indonesia. Kenya also published their review in the Journal of Tropical Microbiology. This was a special issue with selected topics on below-ground biodiversity in Kenya: ISSN 1607-4106 Volume 3 Number 1, October 2004; copyright the Kenya Society of Microbiology.

In addition Indonesia published three brochures and posters for distribution to members of the Indonesian public and to be shared among scientists. Likewise, partners during the BGBD annual meeting produced a total of 71 papers and four discussion papers in ecosystems services, land use intensity quantification, economic valuation of BGBD and data sharing and intellectual property rights.

Books and papers produced by AFNET partners throughout Africa

The following is a list of publications that have been developed in the last one year within AfNet with direct involvement of the coordination office. Most of these papers have been presented in various workshops and are under peer review for publishing while others have been published in refereed journals.

Refereed Journal Articles

Schlecht, E., Buerkert, A., Tielkes, E: and Bationo, A. 2006. A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa (Nutrient cycling in agroecosystems, in press).

Ouattara, B., Ouattara, K. and Serpantié, G., Mando, A., Sédogo, M.. Peters. M. and Bationo, A. 2006. Intensity cultivation induced-effects on Soil Organic Carbon Dynamic in the western cotton area of Burkina Faso. Nutrient cycling in agroecosystems (in press).

Okalebo, J.R,, Othieno, C.O., Karanja, N.K,, Semoka, J.R.M., Bekunda, M.A., Mugendi, D.N., Woomer P.L. and Bationo, A. 2006. Appropriate available technologies to replenish soil fertility in eastern and central Africa (Nutrient cycling in agroecosystems, in press)

Odendo, M., Ojiem, J., Bationo, A. and Mudeheri, M. 2006. On-Farm Economic Evaluation and Scaling-up of Soil Fertility Management Technologies in Western Kenya (Nutrient cycling in agroecosystems, in press)

Kimetu, J.M., Mugendi, D.N., Bationo, A., Palm, C.A., Mutuo, P.K., Kihara, J., Nandwa, S. and. Giller, K, 2006. Tracing the fate of nitrogen in a humic nitisol under different management practices in Kenya (Nutrient cycling in agroecosystems, in press)

Mafongoya, P.L. and Bationo, A. 2006. Appropriate available technologies to replenish soil fertility in southern Africa. Submitted to Nutrient cycling in agroecosystems (Nutrient cycling in agroecosystems, in review)

Book Chapters:

Swift, M.J., Stroud, A., Shepherd, K., Albrecht, A., Bationo, A., Mafongoya, P., Place, F., Tomich, T.P., Vanlauwe, B., Verchot, L. and Walsh, M. 2005 Confronting land degradation in Africa: Challenges for the next decade. ICRAF 25th Anniversary proceedings, Nairobi, Kenya, in press.

Bationo, A., Kihara, J., Vanlauwe, B., Kimetu, J. and Sahrawat, K.L. Integrated nutrient management – Concepts and experience from SSA, in press.

Tabo, R., Bationo, A., Kandji, S., Waswa, B.S., and Kihara, J. Global Change and Food Systems in Africa, in press.

Other Publications:

Bationo, A., Kihara, J,, Waswa, B., Ouattara, B. and Vanlauwe, B 2005 Integrated Soil Fertility Management Technologies for Sustainable Management of Sandy Sahelian Soils. Proceedings of the International Symposium on 'The management of tropical sandy soils for sustainable agriculture- a holistic approach for sustainable development of problem soils in the tropics', November 2005, Khon Kaen, Thailand.

Bado, B., Bationo, A,, Lompo, F., Cescas, M.P. and Sedoso, M.P. Mineral fertilizers, organic amendments and crop rotation managements for soil fertility maintenance in the Guinean zone of Burkina Faso (West Africa). In Press (Springer).

Tabu, I.M., Bationo, A., Obura, R.K. and Khaemba, J.M. Effect of rock phosphate, lime and green manure on growth and yield of maize in a non productive niche of a rhodic ferralsol in farmer's fields In Press (Springer).

Baaru, M.W., Mugendi, D.N., Batiano, A., Louis, V. and Waceke, W. Soil Microbial Biomass Carbon and Nitrogen as Influenced by Organic and Inorganic Fertilisation in Kenya In Press (Springer).

Kimiti, J.M,, Esilaba, A.O., Vanlauwe, B. and Bationo, A. Participatory Diagnosis in the Eastern Drylands of Kenya: Are Farmers aware of Their Soil Fertility Status? In Press (Springer).

Miriti, J.M., Esilaba, A.O., Kihumba, J. and Bationo A. Tied-ridging and integrated nutrient management options for sustainable crop production in semi-arid eastern Kenya. In Press (Springer).

Kihara, J., Kimetu, J.M., Vanlauwe, B., Bationo, A.and Mukalama, J. Increasing land productivity and optimising benefits through nitrogen and phosphorus management in legume-cereal rotations in western Kenya. In Press (Springer).

Kimani, S.K., Esilaba, A.O., Odera, M.M., Kimenye, L., Vanlauwe, B, and Bationo, A. Effects of organic and mineral sources of nutrients on maize yields in three districts of central Kenya. In Press (Springer)

Tabo, R., Bationo, A., Bruno, G., Ndjeunga, J., Marcha, D., Amadou, B., Annou, M.G., Sogodogo, D., Jean Baptiste Sibiry Taonda, Ousmane, H., Maimouna, K.. Diallo and Koala, S. Improving the productivity of sorghum and millet and farmers income using a strategic application of fertilizers in West Africa. In Press (Springer).

Adamou, A., Bationo, A., Tabo, R. and Koala, S. Improving soil fertility through the use of organic and inorganic plant nutrient and crop rotation in Niger. In Press (Springer).

Kaya, B., Nang, A., Tabo, R. and Bationo, A. Performance de diverses espèces agroforestières en jachère améliorée de courte durée et leurs effets sur la fertilité des sols et les rendements du sorgho au Mali. In Press (Springer).

Oral/Poster presentations at conferences:

Bationo, A., Sanginga, N., Kimetu, J., Kihara, J. From Knowledge to implementation: The challenge of the African Network for Soil Biology and Fertility (AfNet).

Bationo, A. Available Technologies for soil fertility Replenishment in East, West and Southern Africa: presentation made during an IAEA workshop on Combating drought held in Nairobi, October 2005.

Bationo, A. Progress Report of TSBF Activities in West Africa.

Bationo, A. Promoting use of Indigenous Phosphate Rock for Soil Fertility "Recapitalization" in the Sahel. Presentation made during the launch of CORAF Funded projects in West Africa.

Bationo, A. The Collaboration between Jordforsk and the African Network for Soil Biology and Fertility (AfNet) of TSBF institute of CIAT. Presentation made in Norway during a visit to enhance TSBF-JORDFORSK collaboration

Sanginga, N., Vanlauwe, B. and Bationo, A. Evaluation of long term agroforestry: Nitrogen and phosphorus use efficiency in the derived savanna in West Africa. Presentation given in Vienna, April 2005, during an Agro-forestry workshop

Bationo, A. Combining rainwater and nutrient management strategies to increase crop production and prevent soil degradation in the Desert Margins of Africa. Presentation given during DMP evaluation meeting in South Africa in May 2005.

Bationo, A., Kihara, J., Kimetu, J. and Waswa, B. The role of the African Network for Soil Biology and Fertility (AfNet) in training and capacity development of young researchers in Africa. Presentation given in Rwanda in February 2005 during a training needs assessment for Rwanda workshop.

Sanginga, N., Bationo, A. TSBFI-CIAT: The New Challenge: Strategy Direction (presented at AfNet FPR-SU training workshop held in Nairobi, Kenya, 19-30th September 2005. Made for a second time during an IAEA workshop on Combating drought held in Nairobi, October 2005.

Output target 2008

- ***Farmer-to-farmer knowledge sharing and extension through organized field trips and research activities result practices in at least two sites***

Work in progress

Strengthening the dissemination process of improved soil management practices of the Quesungual through farmer to farmer exchange

O. Menocal [1], J. Pavón [1], J.L. Olivares [1], M. Ayarza [2], E. Amézquita [2] and M.T. Trejo[2]

[1] Instituto Nicaragüense de Tecnología Agropecuaria, INTA, Nicaragua; [2]Tropical Soil Biology and Fertility Institute of CIAT

One of the main goals of the CPWF- Quesungual project is to extend the benefits of the QSMAS to other hillside regions of Mesoamerica. The Quesungual agroforestry system is now under test for the first time outside Honduras, in neighbouring Nicaragua. During 2005 MIS partners from Nicaragua selected four potential regions for the extrapolation of the Quesungual based on agroecological similarities with respect to the Quesungual site in Honduras. Among these sites, the Rio Dantas watershed in Somotillo was selected as the pilot site for the validation activities of the project.

The process continued with the visit of a group of 20 farmers from Nicaragua to the Candelaria region in Honduras in order to observe the system and talk to farmers practicing the system. During the visit farmers from both countries had an intensive exchange of ideas about the management of the system and the main benefits derived from its use. This was completed by a visit of two Honduran farmers to the pilot site in Nicaragua to demonstrate farmers how to manage trees and plant residues in order to establish the system. This resulted in the establishment of three plots in each of six farms of the watershed. In these plots farmers are comparing the performance of their traditional maize-based management system against the Quesungual system and an intermediate system considering the management of permanent cover crop without burning. These plots have been visited by numerous groups of farmers from neighbouring regions that are interested in the results of the evaluation. So far the system has met the widespread interest and appreciation of participating farmers. Plans to scale up the system to other regions in Nicaragua with the support of INTA and FAO-PESA are under discussion.

Farmer to farmer knowledge sharing and extension of the Quesungual slash mulch agroforestry system (QSMAS)

J. Pavón[1,2], J. L. Olivares[2], G. Bonilla[3], A. C. Calero[3], M. Ayarza[1] and E. Amézquita[1]

TSBF-CIAT; INTA, Nicaragua; UNA, Nicaragua

For the establishment of Quesungual Agro-forestry System in Nicaragua, the first activity was the exchange tour to the community of Candelaria (Honduras), April 04-08 (2005), with producers of La Danta microbasin, the municipality of Somotillo, and producers of Granada, San Dionisio, San Francisco Libre, and young environmentalists from Nicaragua. The pursuable goals in the activity were: the INTA technicians and Nicaraguan producers visited Lempira Sur, to get acquainted of the experiences on the Quesungual Slash Mulch Agro-forestry System (QSMAS), and to begin the validation, the promotion and the diffusion of Quesungual in Nicaragua. A tour was done visiting the different farms and the producers of Honduras. They explained how they established Quesungual and what benefits they have achieved from the system.

For the selection of the QSMAS validation farms (Figure 33), some approaches were considered:

- The importance of the basin
- The access from roads to the farms for data collection
- Suitability of the location for farmer demonstration

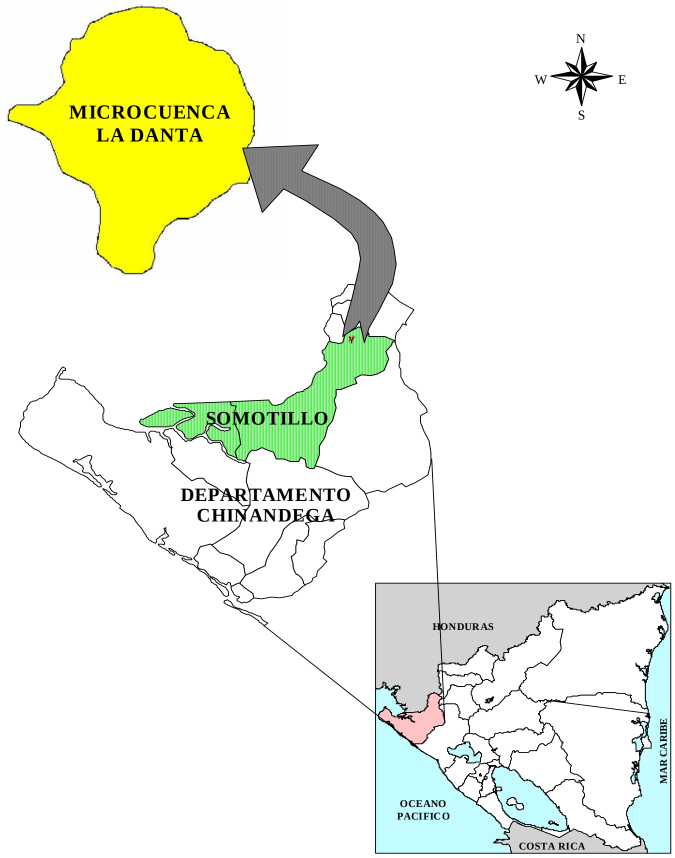

Figure 33. Map of Nicaragua with the general location of La Danta micro basin, Somotillo (Chinandega), Nicaragua. 2005.

- The commitment of the farmer to work in the validation (it implies that he/she should not burn, must manage the tree component, the stubble of the cultivation and have the record of the activities).
- The person must have the tenure of the land (owner).
- Plots that were under at least six years of rest.
- Farm is part of the hillsides agroecosystem.

Sampling of soil in each of the treatments to measure soil physical parameters: This activity was carried out in August 2005 with the collaboration of the Eng. Jeremías Martínez from Honduras; the objective was to evaluate the physical parameters and indicators in the management of the soil.

Field measurement

- Readings of penetrability at different levels of soil depth (0-5; 5-10; 10-20 and 20-40cm)
- Presence of horizons
- Percentage of rockiness
- Compacted layers
- Presence of colors
- Dominant vegetation
- Distribution of roots
- Biological activity
- Percentage of dominant slope

- Description of the soil profile

Sampling for laboratory determinations: Soil cores of 50×50×50cm were opened in each of the treatments (four treatments in total), 12 pits per producer, 500g of soil were collected in plastic bags for chemical analysis, also samples were taken in 5cm × 5cm cylindrical metallic rings for bulk density, 2.5 cm × 5 cm height for humidity retention curves at different soil depths (0-5; 5-10; 10-20 and 20-40 cm).

Vegetation study of La Danta Somotillo microbasin: Regarding the performance of the Vegetation Study of La Danta Somotillo Chinandega microbasin, the following activities were accomplished. Mr. Lester Martin Talle and Mr. Tomás Gutiérrez Vílchez completed the field stage and the cabinet work. The date for the pre-defense of the diploma work was programmed for February 1, 2006. Later on, it will be the defense of the thesis, considering that the vice-dean office gives 15 working days to make corrections to the document.

Activities carried out for the establishment of the treatments:

- An inventory of the tree species within the area selected for the treatment.
- Measure of the treatment areas, according to the specified 900 m^2 for each treatment/producer (4/producter).
- Cleaning of the area in the lower part of the trees (QSMAS) and total cleaning in the treatments of stubble management, and burning of the area and cleaning in the control treatment.
- Selection of the trees that are in the treatments, according to the approach of the farmers
- Elimination of the unwanted trees, and aerial pruning of those that are in the treatment
- Establishment of the annual crop
- Agronomic management (Fertilization with 18-46-0, urea and overgrowth control, samplings of soil, pests, etc.)
- Management of forestry species (pruning)
- Sampling of pests in the soil
- Sampling of soil fertility

Selected plots: By May, the establishment of plots began, also the establishment of the system and the sowing of the first the annual crop (corn). (Table 32).

Table 32. Producers that established validation plots of QAS

Nº	Producer Name	Establishment date	Sowing Date	Crop
1	Jerónimo Herrera	19/05/05	19/05/05/	Corn
2	Santos A Zúñiga	19/05/05	23/05/05/	Corn
3	Ismael Olivas	20/05/05	24/05/05/	Corn
4	Ernesto Pineda	19/05/05	26/05/05/	Corn
5	Roberto Pineda	19/05/05	21/05/05/	Corn
6	Felipe Álvarez	18/05/05	20/05/05/	Corn

Output target 2008

➢ ***Web content in the BGBD website enhanced to contain data and information on BGBD taxonomy and species identification***

Work in progress

The CSM-BGBD project website was launched at the Annual Meeting in Manaus, Brazil (April 2005) and can be accessed at http://www.bgbd.net/. The bgbd website has a Home page from where there is an electronic newsletter, and announcement board and a board that shows upcoming events. Other links include: information about the project, information on the activities of the working groups, the project mailing links and links with other biodiversity sites. Information such as the project structure, the project directory, project governance, project progress reports are all included. The projects publication list is also included on the site.
Brazil also launched its website during the same annual meeting. The site can be accessed at http://www.biosbrasil.ufla.br/. The Biosbrasil site has information presented in Portuguese on the soils and soil biodiversityof the Amazonia Forest. The site also has weather data and announcements targeting the Brazilian community as the main beneficiaries and other would be interested audiences. To see more of what is in the sites anyone is free to click on the links and visit the sites.

Progress towards achieving output level outcome

- *Strengthened and expanded partnerships for ISFM facilitate south-south exchange of knowledge and technologies*

Strengthening partnerships is at the core of TSBF-CIAT strategy to promote ISFM and SLM in the tropics. This year we have restructured AFNET to include regional multidisciplinary teams in Eastern, Southern, and West and Central Africa to better coordinate and interact with the growing membership. The BGBD project completed its first phase with a successful conference in Manaus where 71 southern scientists were able, for the first time, to share results of pioneering inventory work on belowground biodiversity. We have also consolidated the MIS and CONDESAN Consortia in Latin America and have started a new partnership initially in Colombia aimed at restoring degraded pastureland.

AFNET remains the most dynamic and widespread network for linking scientists working on ISFM in Africa. The more than 350 members now benefit from participation in networked long-term experimental trials, degree-related training and capacity building activities (such as the two short courses and land degradation conference organized in 2005), as well as more general information dissemination (such as on training opportunities and scholarships for young scientists, as well as scientific findings and progress in ISFM). South-south exchange of expertise and findings within the network has been visible in the prominent involvement of many AFNET members in the preparation of successful proposals for the sub-Saharan African Challenge Program.

The 3rd annual symposium of the BGBD project, held in Manaus Brazil, provided a forum for the exchange of preliminary data on (i) Benchmark area description and socio-economic characterization, (ii) Results of the inventory of macro-fauna, (iii) Inventory of nematodes and mesofauna, (iv) Inventory of legume nodulating bacteria and arbuscular mycorrhizal fungi (AMF) (v) Inventory of pathogenic and antagonistic fungi and insect pests and (vi) Standard methods for the inventory of BGBD. The innovative pan-tropical research activities of this project were evaluated by a team of external reviewers in 2005, which has translated into a successful restructuring of the project for the launch of a second phase in 2006.

The MIS consortium is very active in advancing the research agenda for the agriculture in Honduras and Nicaragua. The most important achievement has been the strong commitment from partners in Nicaragua to disseminate the Quesungual System into the Country. This is generating very positive synergies between the NARS, the academia, regional and national authorities and of course farmers. Partners of MIS were involved in 4 regional workshops during 2005 and many students have benefited from training that is associated with MIS activities.

The CONDESAN Consortia continues to be a strong partner in the Andes and will be a major vehicle to transfer research outputs, particularly related to implementation of schemes for payment of environmental services. In 2005, a new partnership was initiated with the regional environmental agency in the Caribbean savannas of Colombia, (CVS), the National Research Institution (CORPOICA) and regional Universities (U. Cordoba and U. Sucre) as well as organizations of indigenous communities, to concentrate efforts in the rehabilitation of degraded pastureland in the region. Pasture degradation is perceived as a major problem in the region. This partnership will greatly strengthen the capacity of partners to focus on land rehabilitation and will also include a large number of students from the region at different project phases.

Progress towards achieving output level impact

- *Improved institutional capacity in aspects related to ISFM and SLM in the tropics contribute to agricultural and environmental sustainability*

By involving the principles of ISFM and SLM in the implementation of the activities of the partnerships, we are advancing in reinforcing local and regional capacity to use and disseminate such strategies. Large involvement of students from different disciplines will warrant the continuation of these efforts beyond those of the current partnerships.

In particular, AFNET has been highly effective in placing young scientists and building the capacity of mid-career scientists in advancing ISFM and SLM within African NARES. In preparation for the upcoming 2006 Symposium, a study will be conducted of the disciplinary and career impacts of AFNET members since the network's inception in the early 1990s. The impact of the network is already visible in the regular successes of AFNET members in securing funding for ISFM and SLM work from major donors and initiatives, such as the sub-Saharan African Challenge Program. The networking of leading scientists in various, African agro-ecoregions has already led to significant advances in understanding the dynamics of combining organic and inorganic resources, the interaction of water and nutrients in dryland conditions, and in conservation agriculture.

Output 4
Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems

Output 4: Improved rural livelihoods through sustainable, profitable, diverse and intensive agricultural production systems

Rationale

Intensification and diversification of smallholder agricultural production is needed to meet the food and income needs of the poor and cannot occur without investment in natural resource management, especially soil fertility. Investing in soil fertility management is necessary to help households mitigate many of the characteristics of poverty, for example, by improving the quantity and quality of food, increasing income, and resilience of soil productive capacity. Access to multiple stress-adapted and improved crop varieties and multi-purpose legume species, improved soil and water conservation practices and improved targeting to different categories of farmers, are a few examples of existing interventions.

Investment in improving soil fertility is not constrained by a lack of technical solutions *per se* but is more linked to lack of access to: information for improved decision making and analyzing trade-offs; inputs (e.g. fertilizers, credit and improved germplasm) and profitable markets.

Technical innovation to improve poor people's agricultural productivity can link the goals of improving small farm competitiveness, increasing assets, nutrition and income to the sustainable management of the natural resource base.

Key research questions

1. Which ISFM options are appropriate, where (farm//landscape), and for which farmers (typologies/social capital) to create profitable and resilient agricultural production systems?
2. What are the component and system thresholds for improving resilience of target farming systems?
3. Where and under what conditions does market orientation lead to increased investment in integrated natural resource management (INRM) and improved livelihoods?
4. What information, resources and knowledge do farmers need for improved decision making?

Milestones 2005

- **Decision support tools made available to identify more productive, and profitable and resilient smallholder farm production strategies**

Smallholder farmers face complex decisions on the allocation of scarce resources between different components of their farms due to conflicting demands for their use. Key questions arise at the farm level on resource use such as: How should the limited fertilizer resources available be targeted to different crops and to plots differing in initial fertility? Should all crop residues be used for animal feed, or allocated also for maintenance of soil fertility? Decisions taken by farmers on the use of nutrient resources and their allocation to crops and different fields are influenced by underlying socio-economic factors. These factors vary with the wealth status of the farms. Labour availability and ability to hire labour are major determinants in technologies and production choice by farmers. Choice of crops, their allocation and management is also driven by the need to achieve food security, which is threatened by poor soil fertility, poor access to fertilizers and recurrent droughts. Therefore, technologies attractive to farmers must be within their capacity to provide labour and nutrients, to achieve food security and should also be economically viable. For improved understanding of the multiple constraints that farmers face and the factors driving their decision making processes, there is a need for tools that holistically assess current and optional resource management strategies and that provide comparative analysis of food sufficiency, economic viability and maintenance of soil fertility at the farm level.

One approach CIAT has invested in is a Farm-level analysis of trade-offs between soil fertility management alternatives to improve understanding of complex biophysical and socio-economic factors influencing decision making in smallholder farming systems and to identify opportunities for improving resource use efficiency. A farm characterization (IMPACT) tool, developed by ILRI, linked to a generic (Household) optimisation model was used to evaluate resource use on farms in contrasting wealth categories. The Household model optimised farm productivity based on productivity of crops and livestock, off-farm activities and food sufficiency. Alternatives for management of nutrient resource were simulated using APSIM for the crop production and RUMINANT for the livestock component. The output from the simulation models was fed into the Household model and evaluated within the biophysical and socio-economic boundaries of the farms and used to assess these impacts of change on farm productivity in east and southern Africa.

Highlights

- The use of a herbicide-resistant maize variety and fertilizer reduced significantly the emergence of Striga.
- Four Lablab accessions were identified as the most likely to be accepted by farmers based on their productivity, pest and disease resistance and palatability for human consumption.
- Farmers from Uganda provided with a wider spectrum of dual purpose cowpea lines from which they can choose depending on whether they need grain, fodder or soil improvement.
- Farmer evaluation of improved soybean varieties screened in five locations in Kenya indicated that the variety SB19 can be recommended across locations and that is clearly better than the existing farmers' own variety, Nyala.
- Soil fertility is a good entry point for participatory research on ISFM.
- Households of Western Kenya producing kale for markets had a higher level of food security compared to those growing traditional vegetable crops.
- The creation of awareness of the various attributes of soybeans is currently leading to widespread adoption of soybean among the communities in TSBF-CIAT action sites in Kenya.
- The strategy of integrating research activities with extension oriented to farmers that are committed to use conservation farming practices has facilitated scaling out of minimum tillage technology and green manures cropping in the Ecuadorian and Peruvian pilot watersheds.
- Crop-pasture systems and legume-based pastures increased productivity and profitability of production systems in large and small-scale farms in sandy soils of the cerrados of Brazil.
- The combination of increased soil fertility, adapted crops and market-oriented options has the potential to improve significantly agricultural production and economic profitability of agriculture in hillsides of Central America.

Output target 2006

- ***Crop components and soil management technologies of improved systems promoted by partners in African hillsides***

Work in progress

Participatory evaluation of best-bet options for control of *Striga hermonthica* and declining soil fertility

B. Vanlauwe, L. Nyambega and many farmer groups
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In the context of the project 'Striga control in western Kenya: Raising awareness, containing and reducing the infestation and developing strategies for eradication', supported by the African Appropriate Technology Foundation (AATF), the mandate of TSBF-CIAT is to investigate the containment and eradication of striga infestation through the fusion of different technical approaches. Impact on the soil fertility status and striga seed bank will be quantified. Feedback from active farmer research groups will be obtained through group learning activities on farmer-led testing and evaluation activities with a selected set of technologies.

Fourteen farmer groups were selected in Bondo, Busia, Teso, Siaya, and Vihiga districts, using level of activity, interest in farming, and presence of striga as main criteria. In each of the target sites, the farmer research group selected fields with very high striga occurrence, the latter being validated by field visits during the previous growing season. A set of best-bet interventions, consisting of the components Desmodium intercopping, fertilizer application, IR maize, striga tolerant maize, and herbaceous/grain legume rotation, was exposed to the farmer groups and agreements were made on how to manage the trials and their produce. No financial support was provided for implementation and management of the demonstration trials. A set of group learning activities was developed and is being implemented during the current growing season. During the season, interest at the Teso sites was minimal so these groups were dropped from the project, leaving 11 active demonstration sites.

Maize grain yield data from the 2005 long rainy season (treatments 1, 2, 3, 4, 11, and 12) show that yields in the treatments without fertilizer application were similar and varied between 600 and 1000 kg ha^{-1} (Figure 34). Response to fertilizer was observed for the IR-maize and the push-pull treatments (ranging between 1500 and 1700 kg ha^{-1}) (Figure 34). Striga seedling emergence was substantially reduced in both treatments with IR maize while in the mono-crop and push-pull treatments without fertilizer, Striga emergence was 4-5 times as high as for the treatments with IR-maize. Application of fertilizer to the former treatments increase Striga emergence 7 to 10-fold related to the treatments with IR-maize (Figure 35).

While IR-maize has been observed to seriously reduce Striga emergence resulting in significant response to fertilizer application, maize did not respond to application of fertilizer in the maize mono-crop systems with WH403. In the push-pull systems, application of fertilizer also led to higher Striga emergence but this did not affect the responsiveness of the maize to applied fertilizer. It is not clear at this stage, however, how a young Desmodium crop would have contributed to improved crop yields.

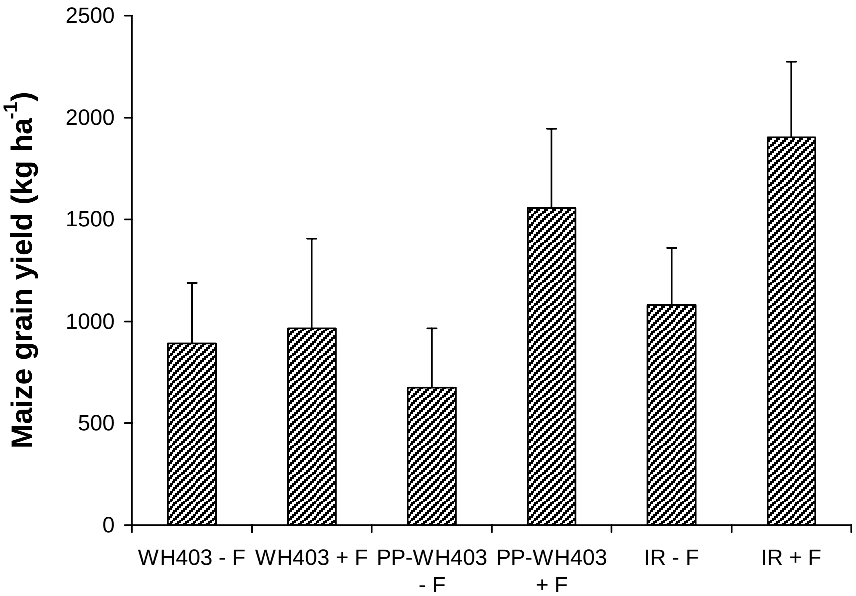

Figure 34. Maize grain yield during the long rainy season of 2005. ‘F’ refers to ‘fertilizers’, ‘PP’ to ‘push-pull’, ‘IR’ to herbicide-resistant maize, and ‘WH403’ to the non-herbicide-resistant maize variety used. Error bars are Standard Errors of the Mean (*n*=11).

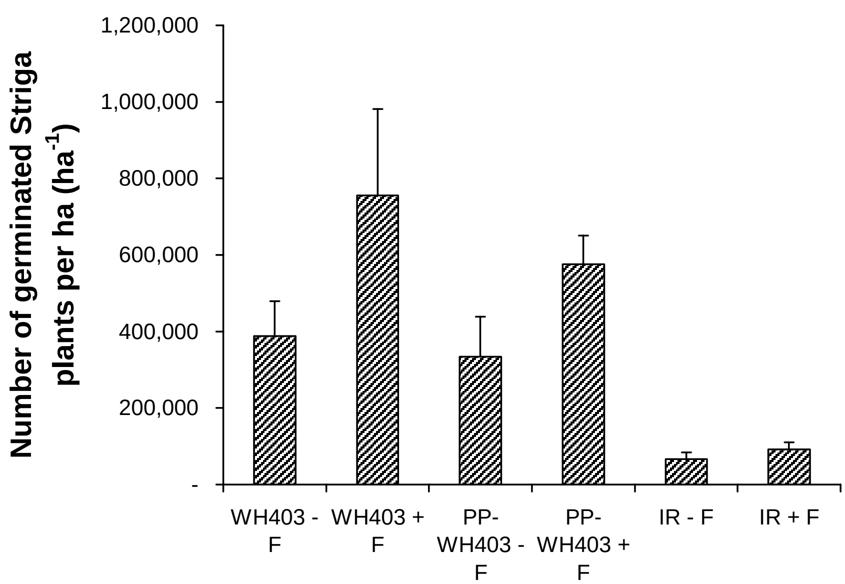

Figure 35. Striga seedling emergence during the long rainy season of 2005. Note that Striga emergence was counted at 6, 8, and 10 weeks after planting and that after each counting event, all Striga seedlings were uprooted. ‘F’ refers to ‘fertilizers’, ‘PP’ to ‘push-pull’, ‘IR’ to herbicide-resistant maize, and ‘WH403’ to the non-herbicide-resistant maize variety used. Error bars are Standard Errors of the Mean.

Building bridges, sharing insights: Making partnerships work for enabling rural innovation in Africa

P. Sanginga and the team

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With the emergence of a broader agenda for agricultural research, coupled with reducing resources, building multi-institutional partnerships has become a core strategy for promoting innovation and achieving greater impact of agricultural research at the household level. However, research efforts to improve our understanding of partnerships and to learn from their successes and failures, are still limited. This study discusses empirical experiences and lessons learned with a multi-institutional partnership, Enabling Rural Innovation' (ERI), in east and southern Africa. The ERI project aims to make agricultural research more client-oriented, demand-driven, and market-responsive. The ERI partnership has grown rapidly from only a few partners in 2000, to more than 13 boundary partners in 2004, while still expanding into new countries in 2005. This study describes the process of building the ERI partnership, and describes a participatory methodology for monitoring and evaluating critical elements of the partnerships. Results show that such elements include: the relationship should be based on a common problem definition and complimentarity of interests in achieving a common goal; strong and consistent support from senior leadership; joint resources mobilization; capacity building, as well as, a range of institutional and individual benefits. Nurturing interpersonal relationships and building social capital, lowers the transaction costs of partnerships, facilitates trust, mutual respect, and regular communication. Evidence of farm-level impacts and individual benefits are key to sustain institutional commitments, and for scaling-up with existing and new partners. Current reforms in agricultural research and development emphasizing participation, farmers' empowerment, and market orientation, also provide a conducive environment for quality partnership. However, sustaining quality partnerships is challenging. This requires creative strategies for coping with staff turnover, over-commitment of field staff, changing organizational expectations, resource limitation, imbalances between institutions and personalities. These challenges also apply to maintaining quality during scaling-up processes, as well as, overcoming the challenges of effective partnerships with private business services sector. Although there are encouraging signs of institutionalization and scaling-up of ERI with existing partners and scaling-out with new partners in new countries, there is still much to learn along the partnership journey.

Output target 2006

- ***Management practice options that increase or maintain BGBD in benchmark agroecosystems demonstrated by partners and farmers in seven tropical countries participating in the BGBD project***

Work in progress

Soil productivity, pest presence including the presence of harmful BGBD will be evaluated against the occurring BGBD and remedial measures to restore soil health using BGBD management strategies will be undertaken. The emphasis will be to use BGBD knowledge gained from the inventory and from experimentation to recommend how BGBD should be best managed to provide selected ecosystem services and to address problems of low soil fertility and inceidences of pests and diseases. This work is expected to increase the resilience of the soils through increased BGBD diversity and abundanced. The work will commence once the project starts implemnting its activities of Phase II during the second half of 2006. All seven participating countries will conduct experiments in joint experiments with farmers and NGOs in elevenbenchmark sites.

Output target 2007

- ***Crop components and soil management technologies of improved systems promoted by partners in acid soil savannas***

Completed work

Development and promotion of soil and crop management technologies in acid soil savannas of Colombia

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The neotropical savannas (243 million hectares) in South America are one of the most rapidly expanding agricultural frontiers in the world. Oxisols predominate in the Colombian savannas and cover an area of 17 million hectares. Out of this total area, 3.5 million hectares are the well-drained savannas known as "Altillanura". Intensification of agricultural production in this agroecosystem requires acid soil (aluminum) tolerant crop and forage germplasm, soil chemical and biological improvement in addition to management of highly vulnerable physical properties. Monocropping systems with high levels of inputs and excessive cultivation (disc harrowing) are not sustainable since they cause deterioration of soil physical, chemical and biological properties as well as escalation of pest and disease problems. Alternative systems incorporating components that attenuate or reverse the deleterious effects of monocultures are required, and biophysical measures of sustainability need to be developed as 'predictors' of system 'health' to sustain agricultural production at high levels while minimizing soil degradation.

Grain legumes, green manures, intercrops and leys are possible system components that could increase the stability of systems involving annual crops. To test the effects of these components on system sustainability and to identify indicators of soil quality, a long-term field study was implemented in 1993 on a Colombian Oxisol in Carimagua under native savanna grassland using a selection of alternatives based on these components. The study was extended through almost two cycles of the principal rotation, i.e., the agropastoral system, recognizing that the degrading or beneficial effects of various agricultural practices are often subtle and only manifest themselves over long periods.

The experimental design was a split-plot with four randomized blocks as replications, with main plots assigned to upland rice-based (fertilizer lime) systems and maize-based (remedial lime) systems. The rice-based system treatments included rice monoculture, rice rotated with cowpeas (for grain), cowpea green manure (GM) and rice-agropastoral rotation. The maize-based system treatments included maize monoculture, maize-soybean rotation, maize-soybean green manure rotation, and maize-agropastoral rotation. A native savanna control was used to measure changes in soil quality. Crop production and soil quality characteristics were measured in two phases. After Phase I (a period of five years with conventional tillage), the plots were split and no-tillage (direct sowing) or minimum tillage (chisel + direct sowing) treatments were introduced in Phase II with an objective to evaluate which agropastoral treatments were suitable for improving soil conditions that are needed for implementing no-till systems. Increasing intensity of production system (with concomitant use of inputs) resulted in changes in soil quality. Soil organic matter declined with increasing intensity of cultivation, as did populations of macrofauna in different systems. Some agropastoral treatments such as cereal-green manure rotation and cereal-improved pasture rotation resulted in improved soil conditions to implement no-till systems.

The above long-term studies were complemented with satellite experiments (at Matazul Farm in the Altillanura) for developing soil management technologies to build-up an arable layer as a precondition to implement no-till systems. The main purpose of building an arable layer is to improve and maintain physical and chemical conditions of the soil in order to favor root growth and soil biological activity.

These experiments were monitored over a four-year period and changes in some physical and chemical properties at different soil depths, plant growth and nutrient uptake as influenced by tillage intensity (1, 2 or 3 passes of chisel) and land use (crop-rotation, agropastoral systems) were measured. Results indicated that agropastoral systems based on acid soil adapted and deep-rooted tropical forage grasses are markedly superior to crop rotation for building an arable layer for infertile savanna Oxisols. Using this integrated soil management technology it was possible to improve profitability and sustainability of agropastoral systems in the Altillanura of Colombia. Adoption studies indicated that the most immediate impact area for the arable layer building technology is the Puerto López – Puerto Gaitán region, which is approximately 180 thousand hectares. It is considered that for its rapid adoption, investment by the Colombian government in improving road infrastructure is critical. In addition, in the more remote areas of the Llanos there are a number of other critical factors (i.e. lack of machinery, inputs, technical assistance, qualified hand labor and roads and communications) that prevent the introduction of crops to establish rotations with pastures in sustainable agropastoral systems.

Output target 2007

- ***Crop-livestock systems with triple benefits tested and adapted to farmer circumstances in hillsides***

Completed work

Improving food security for western Kenyan farm households with integrated soil fertility management for local vegetable crops

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This study analyses the food security in vegetable yields of subsistence households, which were producing kale for market and those, which were cultivating traditional African vegetables (TAVs) for home consumption. By comparing kale-producing households with TAV producing households in terms of the allocation of labour and capital and the coping mechanism enacted to cope with transitory food insecurity, we found that households producing kale have a higher level of food security. This increased food security stems from three key factors: the malleability of kale to be a vegetable and a high-value cash crop; the dedication of all households members to the daily maintenance of kale; and the location of farms adjacent to a water source. These three key factors allow for women to be able to access kale for home consumption, increase the purchasing power of households, and also, boost the total yield of vegetables cultivated on the farm. TAV producing households were found to be vulnerable to an insufficient vegetable supply largely because of geographic location and the overburdening labour demands on the women to singularly produce all household vegetables.

Findings from the study of Luhya and Teso households indicate that crops and the gender division of labour are socially malleable. Kale is able to increase food security because although it is a vegetable it can become a cash crop. This elicits the labour of men in its production and also changes the application of the gender division of labour so that it is no longer taboo for a man to perform tasks within a vegetable/cash crop that are typically done by a woman. The malleability of kale, above being able to employ men's labour, also allowed the enlarged vegetable area to be accessible by women for home consumption because it was also still a vegetable.

Published research results from a nation-wide study analyzing the monetary value of many varieties of exotic vegetable yields produced by small land-holders in Kenya that quantified the food security afforded by the production of kale, showed that only 29 percent of the kale grown by the average small landholder (5 ha) is actually sold. With the remaining 71 percent providing for the entire household, it is not surprising then that we also found kale increases food security through a labour perspective. Though the published study included other ethnic groups in Western Kenya besides Luyha or Teso households, we believe that the data is still applicable because of the similarities in production systems between the ethnic groups.

Work in progress

Farmers' participatory evaluation of a community-based learning process: "Strengthening Folk Ecology" for integrated soil fertility management in Western Kenya

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Farmers and researchers in western Kenya have used community based learning approaches to jointly developed a "dynamic expertise" of integrated soil fertility management (ISFM). This approach builds on farmers' "folk ecology" and outsiders' knowledge, taking action research on natural resource management beyond methods that are descriptive (ethnopedology) or curriculum-driven (farmer field schools). The paper presents and analyses experiences from the on-going participatory monitoring and evaluation of the Strengthening “Folk Ecology” project to document and critique the community-based learning process and its sustainability. Issues include the trade-offs and tensions between science and action-oriented research as well as the true potential of participatory methods for “leveling” power relations between different actors.

Three categories of learning outputs are addressed: a) farmers and researchers learning from experimental results themselves, b) farmers’ learning from the experimentation process, and c) researchers’ learning from the experimentation process.

a) Evaluating research results. Activities have been conducted every season (long and short rains) from 2002-2005. Topics addressed in collective experiments included organic resources, inorganic inputs, cereal – legume rotations, indigenous vegetables. The diversity of follow-up activities at collective and individual levels

Observations on farmers’ experiments: In many cases, the over-simplified experimental design initially preferred by the project undermined the scientific rigor of findings without actually improving clarity for farmers. This allowed for many conflicting interpretations of results, which (for example) confounded local characteristics and land-use history with treatment effects. Farmers and researchers both felt that there was a need to include more farms as replicates in collective experiments to improve the chances that findings could be compared across sites. In all the study sites, farmers’ data collection abilities were quite strong; when these quantitative skills were combined with participatory evaluations it proved to be a powerful learning tool.

Individual experiments were carried out in three different modes: Verifying / validating the findings of collective experiments, modifying technologies to fit new uses, and adapting the technologies to become more convenient or easier to operationalise in the local context. Farmers reported increased confidence in the dynamic expertise that emerged from their collective and individual experiments (which included the use of organic and inorganic inputs, cereal-legume rotation, the role of different soil nutrients and deficiencies, and ISFM for indigenous vegetables). Many technologies outside of ISFM were considered by farmers as part of the “Folk Ecology” project, including Striga control, soil and water conservation, and aspects of crop husbandry or agronomy such as row planting beans (formerly only broadcast). Finally, some farmers had developed erroneous assumptions from their participation, treating experimentation as a “demonstration” of good options (e.g. Stover as a beneficial soil input when it had been included in experiments as a low quality material against which to test high quality ones).

b) Farmers evaluating research process. At the participatory evaluation session held in June 2005, farmers’ groups made comments on the following topics: Communication and feedback, Incentives to participate, Group politics, and Scaling up impacts. Most groups are also now re-baptizing “Folk Ecology” project with local names. To facilitate better learning from experimental results farmers insisted that there be a much faster feedback of data, test results (i.e. of soil and biomass), and of the photos and certificates that were promised by researchers. Other farmers were also faulted for lagging in the sharing of knowledge they gained from study tours, as well as the results of their individual experiments. Among the incentives to participate, many mentioned the idea of setting targets and goals (through organised competitions and prizes). Other problems included the failure of participants to honour their commitments (e.g. times and dates of activities), the need to “cost share” on onerous tasks (with payment or at least provision of lunches or sodas). Participants were also angered that researcher-designed trials employed outsiders as the day labourers when local labour could have been used. Some commentators also wanted the farmers’ evaluations of the researchers to be included in the commendation (or sanctioning!) of researchers by CIAT (e.g. included in our Annual Assessments).

Other comments expressed strong desires for test crops to be broadened beyond maize to include other local staples (millet, sorghum, cassava) as well as local vegetables. Insistence on the importance of local soil types also means extending test sites (and replication) to include this variable. Seed bulking remains a priority activity for farmer groups (and individual experimenters).

c) Researchers evaluating research process. All the project activities are now linked explicitly to a phasing out of activity (end date = 30 June, 2008). This guides everything from building capacity for experimentation to establishing seed supply, group financing strategies, and links with support personnel. Self-organization and funding is being promoted with proposals to local NGOs, marketing and credit activities. It was observed that despite its complexity, soil fertility management is actually a good "entry point" for participatory research and has promoted a wide range of learning and empowerment. The group-based approach does seem to use (and reinforce?) selective pathways of communication and learning, and may not adequately address the most vulnerable community members. The top-down extension model is deeply entrenched both in farmers' and researchers' attitudes (and follows the flow of resources in this and most other TSBF projects); "scientized" language remains a marker of status in many of the interactions. More attention needs to be paid to learning from the group members who have "opted out" of formal involvement.

Impact of agricultural intensification and diversification on crop productivity and soil quality in maize-based hillsides of Central America

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Poverty remains as serious problem in hillside areas of Central America. Large surface of soils have been degraded through erosion or nutrient depletion and through un-adapted management leading to increased poverty. Farmers in Nicaragua expressed in participatory workshops that loss of soil fertility, the lack of crop options and affordable sources of nutrients were major obstacles to increase agricultural productivity. A long-term experiment was established in 2001 at the SOL (Supermarket of options for Hillsides) site at San Dionisio, Nicaragua to develop altenative cropping systems and, to assess their impact on crop productivity and soil fertility (Figure 36).

Figure 36. Overview of the long-term systems experiment at the SOL site in San Dionisio, Nicaragua.

Selected cropping systems were based in the combination of resilient crop germplasm, market oriented options and improved soil fertility management. Table 33 shows the components of these systems. The main purpose of the project is to develop technologies that support sustainable intensification and diversification of cropping systems in hillside agroecosystems. Soils in the site have on average a pH of

6.0, organic carbon 4.9 % and clay content is 40%. Available P is very variable and can range from 5 to 50 mg/kg (Olsen method).

Table 33. Cropping systems and soil fertility management strategies included in the experiment established in 2001 in San Dionisio, Nicaragua.

No	Cropping system	N (kg ha^{-1} year^{-1})	P (kg ha^{-1} year^{-1})
1	Control plot (continuous fallow)	0	0
2	Maize-beans – inputs –cover crop	0	0
3	Maize-beans – inputs + cover crop	0	0
4	Maize-beans + low Inputs – cover crop	30	21
5	Maize-beans + high inputs +cover crop	71	21
6	Maize-beans + high inputs –cover crop	71	21
7	Intensification (maize/beans + sorghum/beans)	71	21
8	Diversification (maize+ green pepper)	71	21

Cover crop: Cowpea (*Vigna unguiculata*).

Treatments were planted in 9 x 9 m plots using a complete randomised design with three reps. A continuous fallow treatment was included in the experiment in order to evaluate the impact of cropping systems on soil fertility parameters over time. The effect of the legume *Vigna unguiculata* as a cover crop was assessed at two N rates (0 and 71 kg N ha^{-1} yr^{-1}). Fertilizer rates applied to the traditional system (30 N and 21 P) are the same as used by producers in the region. Improved crop germplasm was selected from adaptation trials performed in 2000-2001. Green pepper was included as the market oriented crop because of its good prices in the market.

Table 34 shows the grain production and net income obtained in 2004 from the different treatments. Overall results show a significant increase in grain production in the maize-bean systems with the application of 30 kg N and 20 kg P ha^{-1} in comparison to the no input treatments (treatments 3 vs. treatment 1 and 2). Further application of N did not increase crop production probably due to P limitations. Previous experiments performed in the region have demonstrated that there is strong N x P interaction. Increasing the number of crops from two (maize-bean) to four (maize/bean and sorghum/bean) per year increased significantly grain production and economic profitability.

Table 34. Economic impact of alternative production system on grain production and economic profitability per mz[1]

No	Cropping system	Grain yield (kg ha^{-1})	Costs (US$)	Revenues (US$)	Net income (US$)
1	Maize-beans – inputs –cover crop	2411 a	104	175	71
2	Maize-beans – inputs + cover crop	2584 a	124	206	82
3	Maize-beans + low Inputs	6337 b	188	381	193
4	Maize-beans + high inputs +cover crop	7129 b	254	462	208
5	Maize-beans + high inputs –cover crop	7155 b	243	468	225
6	Intensification (maize/beans + sorghum/beans)	8695 c	292	737	445
7	Diversification (maize+ market option)	-	400	1135	735

Mz[1]= 0.75 ha.

Note: values followed by the same letter within the column are not statistically significant the 5% level.

The little effect of the legume cover crop on maize yields in this experiment can be attributed to the limited growth period for biomass production and N accumulation prior to their cutting and planting corn (40 days). Previous experiments have shown a contribution of this legume equivalent to the application of 67 kg N ha^{-1}.

Although farmers participating in the evaluation of the experiment were impressed by the results of including a high value crop in the rotation system, they are reluctant to validate this system because of the high risks involved in the production of green pepper (pest and disease problems) and the higher production costs (twice as much as their maize-bean system with low use of inputs). They are more interested in the intensification treatment. Future plans include the analysis of changes in soil fertility and the establishment of validation plots in farmer fields.

Output target 2007

- ***Strategies of BGBD management for crop yield enhancement, disease control, and other environmental services demonstrated in seven tropical countries participating in the BGBD project***

Work in progress

Green manure impacts on nematodes, arbuscular mycorrhizal and pathogenic fungi in tropical soils planted to common beans

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The management of soil organic matter is crucial to the activities of soil biota. Use of green manures can have multi-faceted beneficial effects on crop productivity arising from increased biological activity and diversity of soil organisms, which in turn can lead to minimized damage and losses from soil borne pathogens, and increased activity of beneficial organisms. However, different sources of green manure can have different effects on the balance between populations of harmful and beneficial organisms; as they have different rates of decomposition, nutrient release and impact on soil moisture and temperature that invariably affects relative population sizes. We evaluated the effect of different types of green manure on three key functional groups of soil biota: 1) pathogens (root rots of beans), 2) microsymbionts (arbuscular mycorrhizal fungi-AMF) and 3) microregulators (nematodes). An experiment was established in 2003 at CIAT's Santander de Quilichao Research Station, using a plot that had a history of high incidence of bean root rot pathogens. The plots were planted with a susceptible bean variety A 70. Immediately after planting, plots were covered with three types of green manure: (1) rapidly decomposing *Tithonia diversifolia* (TTH), (2) intermediate rate of decomposition by *Cratylia argentea*; and (3) slow decomposing *Calliandra calothyrsus* (CAL) at a rate of 6 ton ha^{-1}; and (4) the control (no green manure added). The experiment was replicated five times and samples were collected within and between rows, to measure the effect of the bean plant rhizosphere on soil biota studied. Following 6 cropping seasons, results reveal that application of *Calliandra* increased bean yield, reduced the incidence of root rots, increased AMF hyphal lengths and reduced nematode abundance. For treatments receiving *Cratylia*, minor differences were observed for root rot incidence, yield and nematode abundance, but AMF hyphal lengths were increased when compared to control. Although showing greater AMF hyphal lengths and lower disease incidence, bean yields in plots receiving *Tithonia* were lower than that obtained in control plots. These results highlight the complexity of interactions among soil biota and impacts on crop yields. The potential exists that green manures promote unknown beneficial organisms that can potentially be used to manage root rot pathogens and/or promote plant growth. The full extent of the impact of this study will be realized upon completion of studies to characterize the abundance and functional diversity of microorganisms from this long-term experiment.

Output target 2008

- ***Improved production systems having multiple benefits of food security, income, human health and environmental services identified***

Work in progress

Improved decision making for achieving triple benefits of food security, income and environmental services through modeling cropping systems in Ethiopian Highlands

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Food security in the Enset-based Ethiopian highlands is constrained mainly by land degradation, land fragmentation and limited access to technologies and skills. Enset (*Enset ventricosum*) is a perennial herb with edible corm, supporting about 13 million people in Ethiopia. A household survey, supported by field measurements, was conducted over three years (2000–2002) with 24 representative farmers to identify their production objectives and to quantify their available land resources, cropping system, crop yields and market price, for developing models to facilitate their decision making. Farmers identified three major production objectives depending on their household priorities, socio-economic status and resource base. In Scenario I, farmers were primarily interested in producing enough food from their farm. In Scenario II, they wanted food security and to fulfil their financial needs. In Scenario III, farmers were interested solely in generating cash income, regardless of its effect on food production. On average, the current cropping system is deficit in most nutritional components, and fulfils only 72%, 40%, 35%, 33%, & 25 % of the energy, protein, calcium, zinc and VitA of the recommended daily allowances (RDA), respectively. More over, the net cash income of the current production system was 624 Ethiopian birr cu^{-1} yr^{-1}. Using an optimization model it was possible to fulfil Scenario I by reducing the land area allocated to sweet potato, coffee, wheat and legumes by 11%, 45%, 22% and 63%, respectively and increasing the land area of enset (from 9 to 17%) and kale (from 2.4 to 7.6%). To satisfy Scenario II, there was a need to increase the proportion of coffee, potato, beans and enset by 30, 15, 8 and 3%, respectively, over the current land allocation. This shift would double the cash income, to 1200 birr cu^{-1} yr^{-1}. Scenario III was fulfilled by full replacement of the cereals and root crops by coffee (80.2%) and teff (19.8%), which would generate 2012 birr cu^{-1} yr^{-1}. This option drastically reduced household food production. The change from current production systems to Scenario I offers high quality livestock feed, while Scenario III offers low quality livestock feed whereby about 84% of the feed is coming from coffee husk. Moreover, a shift from the current system to Scenario I would not have any effect on the level of soil erosion, while a shift to Scenario II and III will reduce soil erosion by about 39 and 52%, respectively, mainly as a result of expansion of the area of perennial crops.

Evaluation of 33 *lablab purpureus* (L.) Sweet accessions for agronomic performance and palatability on two contrasting soil types in Uganda, East Africa

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Although preference ranking and logit regression analysis of probabilities of acceptance of 6 different legume cover crops (mucuna, canavalia, lablab, crotalaria, tithonia, tephrosia) graded lablab species with low probability of being accepted or adopted due to its inability to produce sufficient seed and slow initial field establishment, its multipurpose nature has enabled it to come out as one of the legume cover crops that could be highly preferred and probably adopted by farmers because of it ability to provide several farmers' needs (human food, animal feed, mulch, soil nutrients/manure and soil depletion control), at once. Between 2002 and 2005, germplasm for 33 *lablab purpureus* accessions were evaluated through field trials, to identify those that were potentially able to produce sufficient quantities of seeds, hence suitable for adoption. Further evaluation was done through palatability test to identify those accessions that were suitable for human consumption. This palatability evaluation also influenced the acceptance of the lablab by farmers after seeing the other uses to which it can be put. A preference analysis was done to identify those accessions that had a probability of being accepted by farmers. It was determined that four (Lablab Uganda, Njahi, 29400 and Q69887) out of the 33 accessions introduced with the purpose of characterising the new germplasm for conditions in east Africa, especially for high seed yield, were identified as the most likely to be accepted for adoption by farmers based on their consistence better agronomic performance in the field (Kawanda and Tororo) during the two seasons. These accessions had the most preferred palatability characteristics. The second best accessions selected from the palatability evaluations were 29399, 36019, Q5427, Q6988, 31364, 29400 and 30701.

Farmer participatory evaluation of cowpea for soil productivity and food uses

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Dual purpose legumes which offer both reasonable grain yield and biomass for use as fodder or soil improvement, are a new product of research that can offer best bet compromise for farmers needing to improve soil fertility and maintain their cash flow, while ensuring food security. New dual purpose cowpea lines developed by the International Institute for Tropical Agriculture (IITA) were evaluated for provision of grain and fodder in addition to improving soil fertility improvement through N fixation. A set of 14 cowpea lines were evaluated against a local check in an on-station trial in Tororo, eastern Uganda with the objectives of i) establishing the agronomic performance of new cowpea lines in the agro-climatic and farming system environment of eastern Uganda; ii) assessing farmers' preference for the different lines for food, fodder and soil fertility improvement and iii) providing the national grain improvement programme with the opportunity to select lines for further testing and use, either directly as varieties or as sources of breeding materials. Results indicated that the local variety, *Ngori*, had the highest level/probability of acceptance compared to the new lines (the local variety is already acceptable!!!!). The acceptability and logistic analyses showed that out of the 14 new lines evaluated, IT98K-205-8 and IT95K-238-3 were the best genotypes. The agronomic results confirmed the above conclusion. Although, IT98K-205-8 did not have the highest yields, its yields were not significantly different from those from IT95K-238-3, which had the highest grain yields. It was also observed that the line (IT97K-1068-7) which had the highest fodder yield produced the lowest grain yield. Although IT98K-205-8 was the most preferred according to the given criteria, the palatability test indicated that of all the new cowpea lines the most palatable one was IT95K-238-3. Cowpea line, IT95K-238-3 came out as the best lines in terms of palatability, acceptability and yielding potential. At the end of the research farmers who participated in the evaluations selected the best five lines for further evaluation and seed multiplication. This trial therefore, has provided farmers in this region with a wider spectrum of dual purpose grain legume lines from which they can choose from depending on whether they need grain, fodder or soil improvement.

Farmer evaluation of improved soybean varieties being screened in five locations in Kenya: Implications for research and development

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In order to determine the improved soybean varieties that if recommended to the farmers would have a high probability of adoption, a farmer participatory approach was used to evaluate 12 soybean varieties in five locations (Oyani in Migori district, Riana in Kisii district, Kasewe in Rachuonyo district, Akiites in Teso district, and Mabole in Butere-Mumias district) in western Kenya. These comprise of 11 improved varieties (TGX1871-12E or SB4 for short, TGX1895-4F or SB6, TGX1895-33F or SB8, TGX1895-49F or SB9, TGX1878-7E or SB14, TGX1889-12F or SB15, TGX1893-10F or SB17, TGX1740-2F or SB19, TGX1448-2E or SB20, NAMSOY 4m, and MAKSOY 1n) and one local variety (Nyala). Farmers generate all the 17 criteria with which they evaluated the varieties. One hundred and sixteen farmers (52% females) participated in the evaluation. A scoring matrix was used to articulate the results. Data analysis was done using Microsoft Excel. This study shows that of the seven varieties (all are dual purpose promiscuous) tested in all the five locations, only SB19 was acceptable in all (see Table 35). Some of the remaining varieties were acceptable in specific niches (locations), SB9 in Oyani area, Nyala in Kasewe area, SB20 in Teso area, and SB15 in Mabole area. The overall best choices by location are contained in Table 36. This result shows that to avoid the risk of low adoption, a blanked recommendation of varieties that are accepted only in selected niches must be avoided. SB19 is the only variety that can be recommended across locations and that is clearly better than the existing farmers' own variety, Nyala.

Table 35. The best soybean varieties (among the eight varieties screened in all the five sites) based on farmers' evaluation

	Oyani (Migori)	**Riana (Kisii)**	**Kasewe (Rachuonyo)**	**Akiites (Teso)**	**Mabole (Butere-Mumias)**	**All locations**
1st	SB9	SB19	NYALA	SB20	SB15	SB19
2nd	SB8	NYALA	SB19	SB19	SB19	**NYALA**
3rd	SB19	SB8	SB15	SB9	SB4	SB15
4th	SB20	SB4		SB17	NYALA	

Source: Participatory screening data, 2005

Table 36. Overall best soybean varieties by location

	Location				
Rank	**Oyani (Migori)**	**Riana (Kisii)**	**Kasewe (Rachuonyo)**	**Akiites (Teso)**	**Mabole (Butere/ Mumias)**
Overall first choice	SB17, SB19	SB19	Nyala	SB20	SB19
Overall second choice		Nyala	SB19	Maksoy	Nyala
Overall third choice	Nyala	Namsoy 4m	SB17	SB19	SB6

Source: Field evaluation data, 2005

Baseline study on soybeans (production, processing, utilization and marketing) in the farming systems of East Africa (Kenya, Uganda, and Tanzania)

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Soybean was introduced in the farming systems of Kenya, Uganda, and Tanzania many decades ago. However, the crop has remained a minor crop despite its great potentials for improving household food and nutrition security (through quality food supply), household cash income (through the sales of soybean and soybean products), household health (through the provision of high quality protein-rich food), and soil fertility improvement (through its atmospheric nitrogen-fixing ability). Literature indicates that low yield, lack of knowledge on its utilization, and lack of market are among the key factors that have contributed to lack of adoption of soybeans in the farming systems of East Africa. A recent effort based on improved dual-purpose promiscuous soybeans varieties sourced from IITA, Ibadan, Nigeria has been commenced by TSBF-CIAT.

This study aims at documenting the baseline data (on production, processing, utilization, and marketing) in order to have sufficient information to assess the impact of the improved dual-purpose promiscuous soybeans varieties on the soybean sub-sector in East Africa in future. This study is being carried out in selected districts in the three countries. Data for the attainment of the objective of this study are being collected from primary sources (household-level and community-level surveys using questionnaires), secondary sources (reports, published articles, books, etc.) and key informant interviews. Data processing is being executed using many computer applications including Microsoft Excel, SPSS, and SAS.

Data collection for the Uganda arm of the study is currently being executed. Although, data collection for the Kenya arm has been completed, the processing (validation and cleaning, and analysis) of this data is still on going. However, a complete description of the variables (constraints) and the development of the coding schemes related to the constraints have been carried out for the Kenyan data. The implementation of the baseline community-level and household-level socioeconomic data collection in Tanzania is planned towards the end of 2006 or early 2007.

Identification and development of options for sustainable soybean demand and marketing in the farming systems of Kenya

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Soybean was introduced in the farming systems of Kenya many decades ago. However, the crop has remained a minor crop despite its great potentials for improving household food and nutrition security (through quality food supply), household cash income (through the sales of soybean and soybean products), household health (through the provision of high quality protein-rich food), and soil fertility improvement (through its atmospheric nitrogen-fixing ability). Lack of market for the output is one of the key reasons given by farmers for not giving much attention to soybean production. This is compounded by the lack of knowledge on soybean utilization by many farm households. These imply that without proper market development, all efforts towards soybean development and promotion in Kenya will amount to nothing.

This study aims at identifying various ways of developing soybean market at three different levels (household-level, community-level, and industrial level by linking farmers with industries that use soybean) in the farming systems of Kenya. Data from many studies currently being carried out will contribute to this. These include (i) the baseline household-level survey of soybean in the farming systems of western Kenya, (ii) the baseline community-level survey of soybean in the farming systems of western Kenya, (iii) survey of selected food (including supermarkets) and feed industries in Kenya, and (iv) key informant interviews, among others. All these surveys are being executed using structured questionnaire. Secondary data will be derived from reports, published articles, books, etc.

Apart from the above, the processes that we are using to develop the soybean market development at household-level include (i) awareness creation on the various attributes of soybean, (ii) effective promotion through participatory training and development on the processing of easy-to-prepare soybean products and the associated recipes, etc.). At the community-level, our efforts are centered on the *VitaGoat* System (a machine used in soymilk production and the production of soybean residues that are handy in the production of high protein soy bread, soy biscuit, soy cake, livestock feed, etc.). At the industrial level, our activity is on linking farmers and producer groups to large-scale food and feed industries (to ensure the existence of market opportunities that can mop up production levels that are beyond the absorptive capacities of the household- and community-level demand and help in import substitution that can save the huge foreign exchange often spent by these industries to import soybean for their operations in Kenya

The awareness creation is currently leading to widespread adoption of soybean production among the communities in TSBF-CIAT action sites in Butere-Mumias and Migori Districts. A VitaGoat has been imported from Canada, especially for community-level soymilk processing and the generation of soybean residues for use in the production of other soybean products. Many industrial processors of soybean in Kenya, including Bidco and NUTRO EPZ have agreed to clear the market for whatever soybean that the Kenyan farmers produce and at Ksh 26 per kg.

Evaluation of key agricultural production input supply and network in the farming systems of western Kenya

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Low factor (land, labor, capital, management) productivity is a common feature of the farming systems of western Kenya. This negatively affects livelihoods by impacting negatively on household food and nutrition security. Among the other reasons, lack of access to key agricultural production inputs (inorganic fertilizers, organic inputs, seeds, etc.) by the smallholder farmers has been blamed for the low factor productivity that characterize western Kenya agriculture. The situation is further compounded by the HIV/AIDS pandemic that is most widespread in western Kenya compared to other regions of Kenya.

The objectives of this study are to (i) assess the availability farm input supply centers in selected districts in western Kenya, (ii) to evaluate the types and suitability of agricultural inputs stocked, (iii) to assess the types and qualities of other services that farm input suppliers offer to the smallholder farmers, and (iv) to make recommendations on how to improve the access of smallholder farmers to agricultural production inputs in the farming systems of western Kenya and similar environments.

This study is being carried out in eight districts from three provinces (Western, Nyanza, and Rift Valley) in western Kenya. These districts were randomly selected from the list of all the districts in the three provinces. In each selected district, a list of all the agricultural production inputs was compiled. From this list, a random sample of input suppliers was selected for interview using structured questionnaire. Secondary data sources include reports, published journal articles, proceedings of conferences, books, etc. Data processing is being carried out using Microsoft Excel, SPSS, and SAS.

Data processing is still at a primary stage.

The place of soybean among the grains (grain legumes and cereals) traded in selected marketed markets in western Kenya

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Literature, interactions with farmers and key informants have revealed that lack of market (and low prices) has been a major reason for the low presence of soybeans in the farming systems of western Kenya. This is compounded by lack of knowledge on simple methods of processing soybeans for food, making marketing the product the only option left for the producers.

The objective of this study is to (i) assess the degree of availability of soybean in the selected markets in western Kenya, (ii) to determine the types and sources of different soybean varieties found in the markets in western Kenya, (iii) to evaluate the stock and market shares of soybeans relative to the other grains traded in the markets in western Kenya, (iv) to evaluate the marketing margins associated with soybean marketing in the markets in western Kenya, and (v) to make recommendations on how to increase both the marketing margin associated with soybean marketing and the market share of soybeans compared with the other grains.

This study is being carried out in eight districts from three provinces (Western, Nyanza, and Rift Valley) in western Kenya. These districts were randomly selected from the list of all the districts in the three provinces. In each selected district, a list of all the markets where grains (including soybean) are traded is compiled. From this list, a random sample of markets was selected. At the market, the traders selling grains are listed and a random sample is taken and interviewed using structured questionnaire. Effort is made to include large and small stock traders in the sample. Secondary data sources include reports, published journal articles, proceedings of conferences, books, etc. Data processing is being carried out using Microsoft Excel, SPSS, and SAS.

Scaling out conservation farming experience in Fuquene (Colombia) to other Andean watersheds: Ambato (Ecuador) and Jequetepeque (Peru)

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The Colombian experience with conservation farming practices (minimum tillage, green manures and direct drilling) is being scaled-out by a strategy that aims to test and adapt the technology to the Peruvian and Ecuadorian production system. During 2005, training courses oriented to Jequetepeque (Peru) and Ambato (Ecuador) farmers interested in implementing the proposed technological change. In Peru, strategic alliances between the project local partner (CEDEPAS) and the farmers were created in order to establish pilot farms with green manures and minimum tillage. Complementary research activities are conducted in order to measure the impact of these practices on soil physical properties and crop diseases. For 2006, pilot implementation of these soil conservation practices was agreed between a community-based organization and the project in Ecuador. The monitoring of impacts will be measured by CONDESAN and CIAT. It is expected to extrapolate conservation farming practices in 100 ha of the Ambato watershed (Ecuador).

Output target 2008

- ***Crop-livestock systems with triple benefits tested and adapted to farmer circumstances in savannas***

Completed work

Sustainable intensification of crop-livestock systems on sandy soils of Latin America: trade-offs between production and conservation

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Large areas in Latin America are covered by coarse-textured (sandy) soils that are under extensive livestock systems, annual cropping systems and forest plantations. Low levels of soil organic matter and limited availability of water and plant nutrients, in particular phosphorus and nitrogen, are the major soil constraints to agricultural productivity. These sandy soils are also highly susceptible to massive topsoil losses through wind and water erosion. Because of this, large and small-scale farmers face the challenge of developing sustainable agricultural systems in this type of soils. The present study discusses the technical potential and socio-economic viability of two resource management technologies that were developed in the Brazilian Cerrados to enhance livelihoods of small and large farmers and productivity of sandy soils: crop-pasture systems with high use of inputs and legume-based pastures for dairy systems with low use of inputs. These technologies were developed, tested and monitored with the active participation of individual farmers, local organizations and researchers from EMBRAPA and CIAT. The two technologies described in this paper increased productivity and profitability of large and small-scale production systems in the short-term and improved resource conditions in the long run. In spite of their economic and environmental soundness, their massive adoption is constrained by socio-cultural factors, the lack of economic incentives and continuous technical backup and policies to support sustainable intensification of these soils.

Progress towards achieving output level outcome

- *Partners promoting resilient production systems with multiple benefits (food security, income, human health and environmental services)*

Farmers in Africa and Latin America are evaluating actively crop components and management technologies having benefits on food security, income generation and soil fertility. Improved lines of Cowpea and L*ablab purpureus* have been selected by farmer groups in Kenya and Uganda for their contribution to human consumption, increased fodder availability and improved soil fertility. Small farmers in the Cerrados of Brazil are increasing milk production by introducing drought-tolerant forage legumes in their pastures. Market-led crop options such as soybean and vegetables will play a major role in generating income for small farmers in Africa, provided that sustainable markets are developed and alternative uses explored. Preliminary results are promising. The combination of resistant maize varieties and improved soil fertility is showing potential to reduce Striga emergence in maize fields in western Kenya.

Progress towards achieving output level impact

- *Improved resilience of production systems contribute to food security, income generation and health of farmers*

The new production systems under development by the TSBF team and their collaborators in Africa and Latin America will have a positive impact on crop productivity and profitability in the short term. This will be translated into improved food availability at the household level and greater chances to link agricultural production of smallholder production systems with market demands. Soybean crop will become an important component of production systems if production, processing and marketing bottlenecks are solved.

Output 5
Sustainable land management for social profitability developed, with special emphasis on reversing land degradation

Output 5: Sustainable land management for social profitability developed, with special emphasis on reversing land degradation

Rationale

Strategic and component research to date has been conducted largely at the plot or field scale, where interactions among various agricultural enterprises are seldom considered. Although TSBF-CIAT's strength remains at the plot level, the diversity of forces impinging on the plot naturally draws attention towards a hierarchical systems-based approach. The next generation of work will be at higher scales, particularly the farm and landscape scales. The rationale for working at the farm scale is the need to improve nutrient use efficiency through better allocation of the limited organic and inorganic resources among different enterprises, taking into consideration inherent soil variability within the farming system. Inadequacies in supplies of both organic and inorganic nutrients have created strong fertility gradients even within the smallest farms. Smallholder farmers typically remove harvest products and crop residues from their food producing 'outfields' and devote their scarce soil inputs to their smaller market 'infields', resulting in large differences in soil productivity over time between these two field types. Understanding how to manage the limited nutrient supplies across such fertility gradients is a key component in raising productivity in fields of staple crops.

Interest in the quality and health of soil has grown with the recognition that soil is vital not only to production of food and fiber, but also the smooth functioning of the ecosystem, and overall environmental stability. Agriculture needs economically viable and ecologically sound soil management practices that provide sufficient food and yet maintain environmental stability, ecological integrity, and the quality of essential resources. Strategies for sustainable management include conserving essential soil components, minimising erosion, balancing production with environmental needs, and making better use of renewable resources. In this regard, soil health is a major indicator of sustainable management. Criteria for indicators of soil health are useful in defining ecosystem processes and sensitivity to managements and climatic variations and in integrating physical, chemical and biological soil properties. Numerous experts *e.g.* agricultural specialists, producers, conservationists, and policy makers, etc might extensively need those criteria and data for sustainable management practices. Although soils gain certain biological, chemical and physical properties within a given ecosystem, the ultimate determinant of soil productivity, sustainability and health is the land manager. The assessment of health and quality of soil is the primary indicator of sustainable management and environmental remediation. Examples given include approaches for assessing soil health, defining the economic and environmental sustainability of land management practices, and translating our science into practice.

Environmental services, particularly hydrological response and soil erosion control, can be managed effectively only at larger landscape scales. Research at the watershed scale is critical in the tropical regions, and given that projections indicate that eastern and southern Africa, and Central America will be critically short of water in the coming decades, extending TSBF-CIAT's research agenda into this area is warranted. Research projects funded by the Water and Food Challenge Program for the Volta in West Africa basins and on the Quesungual systems in Central America offer the opportunity to address constraints related to water and its interaction with soil fertility and other environmental challenges. Research conducted with partners in regional networks and consortia and the GEF-UNEP funded BGBD project will contribute to development and promotion of sustainable land management (SLM) practices.

To see ISFM principles applied by a wide variety of actors at scales ranging from the farm level to the national or continental levels means addressing the problems of how to use knowledge gained at one scale to interpolate or extrapolate knowledge for decision making at another scale. In recent years TSBF and other natural resource management programs have confronted the challenge of extending their research findings for successful impact on farm. Conveying the numerous components and complexity of interactions involved in natural resource management is very different from the extension of new crop varieties through demonstration plots. In the latter, the results are quick and easy to see, whereas the results and possible benefits of natural resource management strategies may not be readily apparent and often take time to manifest themselves. The rise of the participatory movement in agricultural research has also emphasized the importance of responding to farmers' perceptions and needs rather than assuming that formal science provides solutions in its own right.

Key research questions

1. What is the minimum set of social, economic and biophysical indicators for preventing and reversing land degradation?
2. What are the drivers of land degradation?
3. Does hot-spot management provide a driver for wider-scale investment in ISFM?
4. What are the stakeholders, technologies and incentives necessary to enable SLM?
5. What are the global benefits (ecosystem services) from SLM?

Milestones 2005

No milestones listed for this output in the CIAT Medium-Term Plan 2005-2007.

Highlights

- Preliminary data from a study in Kenya, Ghana and Zimbabwe to assess the interaction between organic resource quality, aggregate turnover, and agro-ecosystem nitrogen and carbon cycling, showed substantial effects of organic resource quality on crop performance. The quality of the applied organic resources also appeared to influence the presence of large macro-aggregates in the well-structured Embu soil.
- The watershed analysis approach using Hydrological Response Units (HRU) has been useful for targeting Fuquene and Altomayo watershed areas where certain land use or management alternatives are profitable for the farmer and can modify positively the environmental externalities.
- ECOSAUT model is a multicriteria tool that enables the user to understand, measure and valuate the trade offs between economic and social benefits caused by a land use alternative and its environmental impact. Its use in the Altomayo watershed in Peruvian Andes, concluded that among several alternatives to reduce soil erosion, which increases water treatment costs, the adoption of coffee under shade is the most suitable option. Though the effect of erosion is lower than other alternatives, this result in lower total investment required to implement and it would also recover the investments sooner. Additionally it generates added value in terms of creating jobs.
- In the Fuquene watershed (Andean highlinds of Central Colombia), conversion of native land cover (Mountain forest and Paramo vegetation) into cropland or pastures has resulted in an estimated loss of soil carbon in the range of 50–80 TgC during the last century.
- Conversion of native land to crops or pastures in the Fuquene watershed resulted in a net decrease of the capacity of the soil to consume atmospheric methane thereby impacting negatively the function of the soil as a net sink for greenhouse gases. The use of nitrogen fertilizers in pastures and in crops increases net emissions of N_2O into the atmosphere as compared with the native land cover (Forest and Paramo vegetation). Total N_2O emissions accounted for 2-3% of applied N.
- Support to CENIPALMA in the systematization of soil data in a GIS-linked database was completed in 2005 and outscaling of the tool was initiated in 2006.

- A regional workshop was conducted in Honduras to bring together natural and social scientists from different countries to apply the *Dahlem Desertification Paradigm to* land degradation and recovery of steepland agricultural systems in Central America. Main drivers (both biophysical and socioeconomic) for adoption of the Quesungual slash and mulch agroforestry system were identified and a conceptual model was developed.
- A project to rehabilitate degraded lands through silvopastoral systems and reforestation with native timber species in the Caribbean savannas of Colombia, was successfully negotiated with the Biocarbon Fund. The project will generate significant employment and will enhance livelihoods of poor rural communities including native Indian groups. The Project will generate 0.7 Gg CO_2 equivalents over a 25-year period and will generate CERs (certificates of emission reduction) that could be traded in the emerging carbon markets as part of the Clean Development Mechanism (CDM) of the Kyoto Protocol.

Output target 2006

- ***Potential for carbon sequestration estimated for at least one tropical agroecoregion***

Work in progress

Interaction between organic resource quality, aggregate turnover, and agro-ecosystem nitrogen and carbon cycling

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The management and enhancement of soil organic matter (SOM) is pivotal to the sustainable utilization of soils. SOM is a major determinant of soil fertility, water holding capacity and biological activity and is highly correlated to levels of above and below ground biodiversity. A loss of SOM can lead to soil erosion, loss of fertility, compaction and general land degradation. In addition changes in the use and management of soils that result in a decline in SOM can lead to a release of CO_2 to the atmosphere, with practice that increases SOM leading to sequestration of C from the atmosphere to soils. The management of SOM is therefore important at the field, regional and global scale. Important factors affecting the quality and quantity of SOM are climate, soil texture, and organic resource quality of the inputs. The Decision Support System for Organic N management distinguishes 4 classes of organic resources with varying quality. In the current activity, the focus relates to how interactions among organic resource quality, mineral N inputs, and rate of soil aggregate turnover control C and N cycling in natural and agroecosystems across different soil textures and climatic zones. The overall objectives are: (i) to elucidate the linkage among organic resource quality, organic plus mineral resource additions and aggregate turnover, (ii) to determine how this linkage controls C cycling and the use efficiency of N derived from both organic and mineral resources, and (iii) to determine how this linkage varies across soil textures and climates.

To address above objectives, two sets of experiments have been initiated. First, a multilocational field trial has been established in Kenya in Kenya (sub-humid, bi-modal climate), Ghana (humid, bi-modal climate), and Zimbabwe (semi-arid, mono-modal climate) with the following factors and levels: organic resource quality [*Tithonia diversifolia* or *Crotalaria ochroleuca* - Class I, Calli*andra calothyrsus* or *Leucaena leucocephala* - Class II, Maize stover – Class III, Sawdust – Class IV, and Manure], fertilizer [with and without 120 kg N/ha], and organic matter application rate [1.2 and 4 ton C/ha]. In each of above countries, one trail has been established on a relatively heavy and one on a relatively light soil. The trials are currently in their 8th cropping season in Kenya (2 seasons per year), in their 6th season in Ghana (2 seasons per year) and in their 3rd season in Zimbabwe (1 season per year).

Secondly, a decomposition tube experiment with single (^{13}C or ^{15}N) or double (^{13}C and ^{15}N)-labeled organic resources and/or fertilizer was set-up in April 2005, in Embu, Kenya. Tubes were designed that allow measurement of N_2O and CO_2 production and the capture of mineral N at the tube base using anion/cation exchange resins. Subsets of the tubes were harvested at 2, 5, and 8 months after installation and are currently being processed for SOM fractionation and other analyses.

For SOM fractionation, aggregate size classes (>250, 53-250 and < 53 µm) are separated by slaking. To isolate the light fraction the macro- and microaggregate size classes are suspended in 1.85 g cm^{-3} sodium polytungstate. After flotation of the LF, the heavy fraction (HF) of the microaggregates is dispersed in a hexametaphosphate solution (5 g l^{-1}) and passed through a 53-µm sieve to isolate intra-aggregate particulate organic matter (POM). To isolate the microaggregates out of the macroaggregates a newly developed microaggregate isolator, which breaks up macroaggregates while minimizing the breakdown of released microaggregates, is used. Macroaggregates are immersed in deionized water on a 250-µm mesh screen and shaken with glass beads. To ensure that microaggregates are not exposed to further disruption by the shaking, water flows continuously through the device and the micro-aggregates are flushed immediately onto a 53-µm sieve. Once all the macroaggregates are broken up, the material on the 53-µm sieve is manually sieved to ensure that the isolated microaggregates are water-stable. The inter-microaggregate POM, retained on the 53-µm sieve together with the microaggregates, is isolated by density flotation. After density flotation, microaggregates are dispersed in hexametaphosphate and intra-microaggregate POM is isolated by sieving.

Results from the first season after application show clear differences in net response to application of the organic resources for the organics resources belonging to Class I and II (Tithonia, Crotalaria, Calliandra, Leucaena) and for those belonging to Classes III and IV (Maize stover, sawdust), with the latter resulting in lower net increases in maize grain yield – often even decreases – relative to the treatments with Class I and II organic resources applied (Figure 37). Manure results in intermediate net increases, depending on the site considered. Preliminary wet sieving data form the Kenya and Machanga sites, obtained from soil samples taken after 6 seasons, show large treatment-related differences in large macro-aggregate contents (> 2 mm) for the Embu site (Figure 38a). The control contained less large macro-aggregates than all other treatments, except for the treatments 'Maize stover + fertilizer' and 'Sawdust – fertilizer'. In the treatments with the latter two organic inptus, application of N fertilizer substantially changed the concentration of large macro-aggregates, which was not true for the other organic inputs. Concentrations of macro-aggregates between 2 and 0.25 mm were not different between treatments for both the Machange and the Embu sites (Figure 38b).

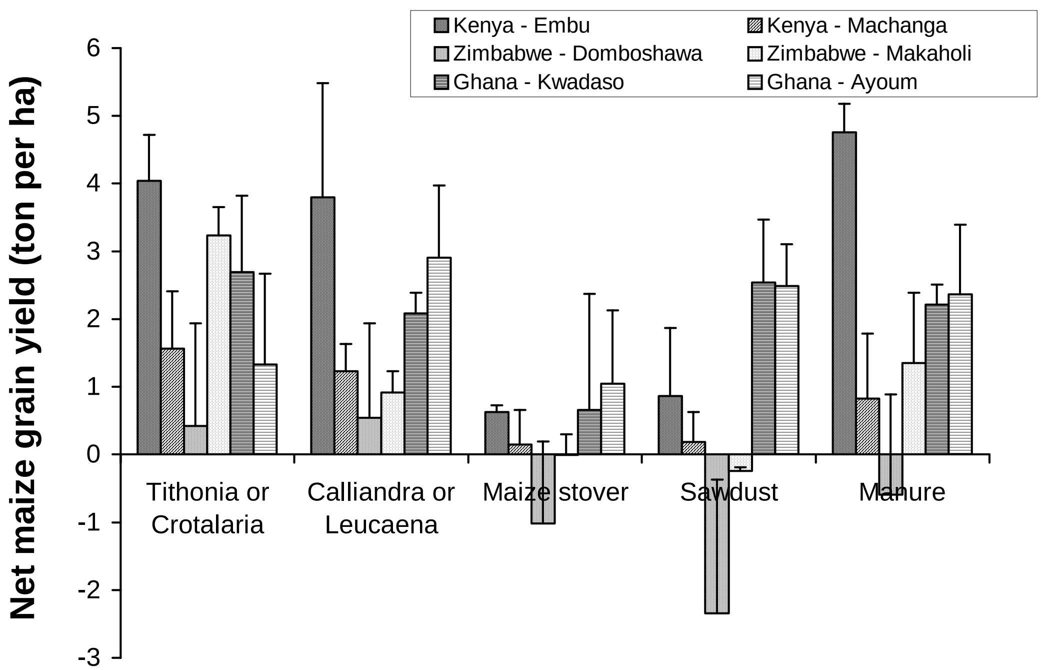

Figure 37. Net response (relative to the no-input control) to added organic resources of varying quality during the first season after their application on the relatively heavy (left side of the legend) and relatively light soils (right side of the legend) in Kenya, Zimbabwe, and Ghana. Note that only the data for the high application rate (4 ton C ha^{-1}) in absence of N fertilizer are presented. In Kenya, Tithonia is used as a Class I organic input while in Ghana and Zimbabwe, Crotalaria is the Class I material used. In Kenya and Zimbabwe, Calliandra is used as a Class II materials, while in Ghana, Leucaena is the Class II material used. Error bars are Standard Deviations.

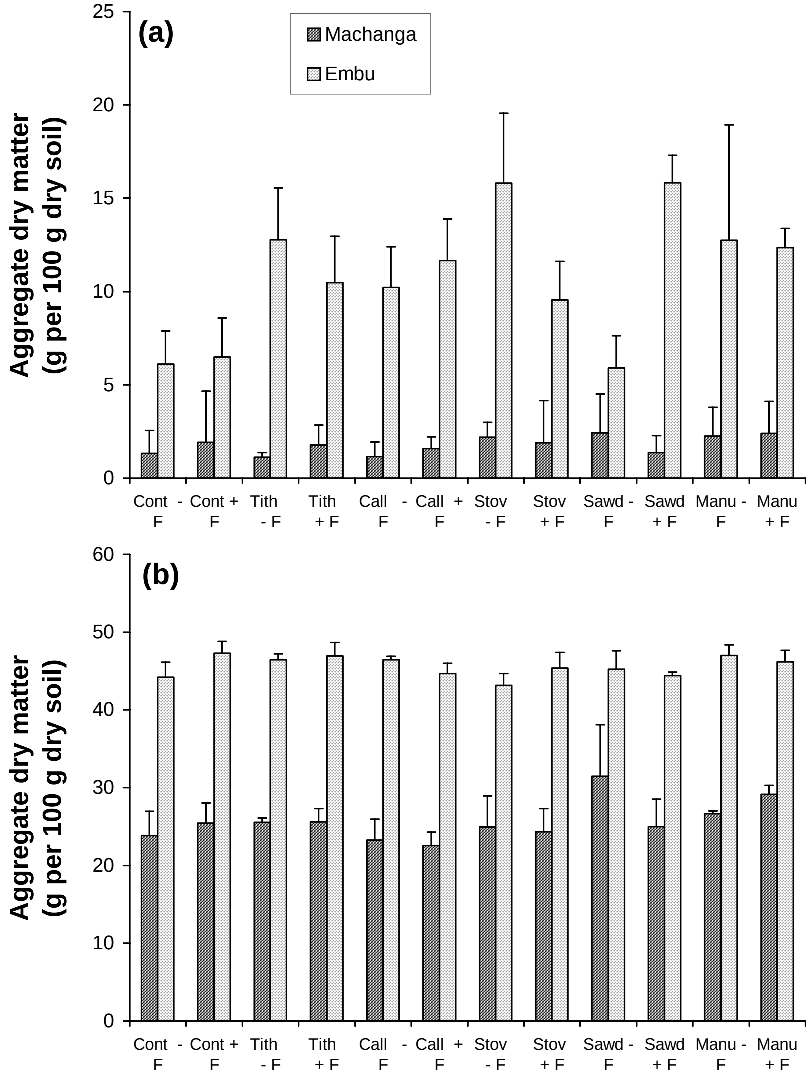

Figure 38. Concentration of aggregates >2 mm (a) and between 2 and 0.25 mm (b) for the Embu and Machanga sites, as affected by organic resource quality and fertilizer application. 'Cont' means 'Control', 'Tith' means 'Tithonia', 'Call' means 'Calliandra', 'Stov' means 'Maize Stover', 'Sawd' means 'Sawdust', 'Manu' means 'Manure, '+ F' means 'With fertilizer' and '- F' means 'Without Fertilizer'. Error bars are Standard Deviations.

Preliminary data show substantial effects of organic resource quality on crop performance, thereby respecting the principles outline in the Decision Support System for Organic N management. The quality of the applied organic resources also appeared to influence the presence of large macro-aggregates in the well-structured Embu soil, although application of fertilizer appears to alter their presence for the lower quality organic resources (maize stover, sawdust). Further fractionation of the macro-aggregates will reveal detailed information regarding aggregate turnover within the studied systems.

Payment for environmental services in the Fuquene watershed (Colombia): carbon stocks and fluxes of greenhouse gases

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The Water and Food challenge program approved to CONDESAN a project to pursue the "Payment from environmental services as a mechanism to promote rural development in the upper watersheds of the tropics". Environmental services considered include the provision of water, biodiversity conservation, prevention of soil erosion and potential for mitigation of net emission of greenhouse gases (GHG) and carbon sequestration. The project will operate in a group of nine pilot watersheds in various Andean countries. The Fuquene Watershed in the central part of Colombia, near Bogota, was selected to initiate the project and to test methodologies that later will be used in the assessment of the other watersheds. The Fuquene lagoon collects the water from the watershed and provides water to a vast number of villages and agricultural fields in neighboring areas. Despite numerous governmental, bilateral and private projects that have operated in the watershed, the lagoon, suffers an accelerated rate of reduction in area/water volume as well as eutrophication, due to several factors including border land recovery by ranchers, pollution of incoming water with sewage sludge, animal manure and nutrients leached from fertilizers etc. The watershed covers an area of 187000 ha. Main production activity in the watershed is intensive cattle raising. The most productive dairy farms in Colombia are likely located in this region. Total area covered by pastures (mainly Kikuyo grass in the lower basin and Ryegrass in the medium to upper part) is 110000 ha (59% of the area). Potato is the main crop in the watershed and is usually managed with conventional tillage, that involves major soil disturbance which promotes soil erosion and nutrient leaching. Total area under crops is around 48000 ha (26% of the area). In recent years as a result of activities from a GTZ project, no tillage systems have been promoted and are slowly gaining acceptance by potato growers. To date, there are some 4000 ha of no till potato now in the watershed.

Our contribution to this project includes the quantification of the status of the most important soil physical characteristics that regulate soil function in relation to water, nutrient storage and leaching. We have also assessed total carbon stocks in soils as well as net fluxes of carbon dioxide, methane and nitrous oxide in the watershed for the dominant land use systems. The purpose is to identify the land use systems that are more beneficial or detrimental to the environment. This information will be contrasted with information on sustainability of land use and the socioeconomic of main production systems collected by other researchers as part of the project. Win-win systems could then be promoted to help policy makers and local authorities to reorder land use in the watershed to maximize benefits for local farmers and communities as well as for neighboring receivers of water and services and for the global environment.

Seven dominant land use systems on similar soils (hydrologic response units-HRU) were selected to fall within four transects: one longitudinal transect crossing the watershed from south to north and three perpendicular transects distributed along the main axes to spread along the watershed. Selected HRU included: Paramo native vegetation, mountain secondary forest, potato crops under conventional and minimum tillage, Ryegrass pastures, Kikuyo intensively managed pastures, and degraded land that not longer supports productive uses. Although, as can be seen in Figure 39, several land use cover are present in the watershed, the selected HRU account for at least 95% of the area of the watershed. These selected HRU were replicated three times trying to cover the spatial variability found in the watershed. A total of 21 sampling plots were selected.

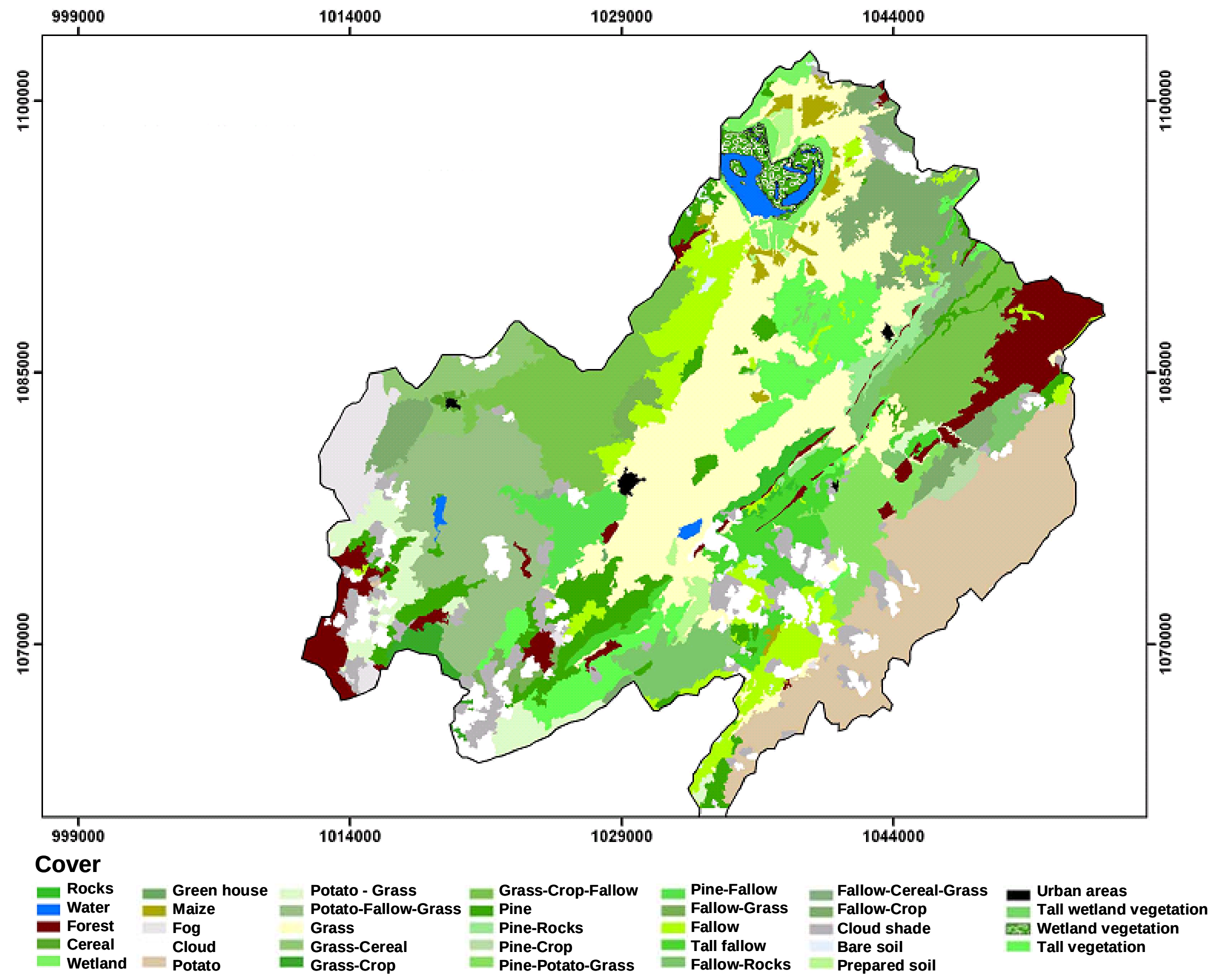

Figure 39. Land cover at the Fuquene watershed, Colombian Andean highlands.

Soil C stocks: In each of the 21 plots, three soil pitches (0.5 × 0.5 × 1m) were open: pitches were located at three altitudinal positions within each plot. Upper part, medium and lower part of the plots. In each pitch, composite soil samples were collected at four depths (0-5, 5-20, 20-40, and 40-100 cm) to measure bulk density and determine total Carbon stocks in soils. Soil samples were analyzed using conventional wet oxidation methods to assess oxidable carbon and by CHN analyzers to measure total carbon. In areas where the history of land conversion from C3 type dominated vegetation (i.e native forest) to C4 dominated species (some grasses, maize, sorghum etc), or from C4 into C3 vegetation, is well known and reliable, ^{13}C determinations were also made in soil samples to assess the rate of replacement of new organic matter and to establish C partitioning between soil pools of different mean residence times.

Soil Physical parameters: At the time of soil sampling, some soil physical characteristics were evaluated in situ: resistance to penetration in the soil profile using a penetrograph and soil shear strength (torcometer). Samples were collected for bulk and particle density determinations measuring saturated hydraulic conductivity, air permeability, resistance to compaction, and water retention characteristics. Some results of the soil physics parameters were presented in the 2004 annual report. As physical condition define how water can be store and move into the soil profile, a good understanding of the behavior of the physical soil profile in relation to water fluxes will allow to define if there are possibilities of contamination with elements coming from fertilizers or not. As also they define, the hydrologic response of the soil in relation to rainfall, they will allow to understand the relationship between rainfall and rainfall acceptance capacity of the soils, runoff production as well as the vulnerability of soils to be eroded. This knowledge will help to track sources of contamination of the lagoon and the loss of the water mirror and will be used to define solutions to control degradation problems.

Greenhouse gases: fluxes of carbon dioxide, methane and nitrous oxide, the three most important GHG related to land use change and agricultural activities, were monitored over one year period to follow at least a full cycle of climatic variations. One of the replications for the seven HRU was selected for monitoring gases. In each plot four replicate sampling points were selected and geo-referenced. A PVC collar (30 cm diameter, 10 cm height) was permanently installed in the soil to a depth of 8 cm. A closed vented chamber is attached to the collar at the time of gas collection. Four gas samples are collected per chamber at times 0, 10, 20 and 30 minutes. Chamber temperature is measured at every sampling time. A biweekly sampling frequency was used. Gas samples were stored in pre-evacuated glass vials and were analyzed within two weeks after collection by gas chromatography (ECD and FID detectors) for CH_4, CO_2 and N_2O. Gravimetric soil water content was measured at every sampling time. Soil redox potential, pH and soil temperature was measured in situ.

In Figure 40, data on total soil carbon stocks are presented for land cultivated with potato using contrasting tillage methods (conventional, highly disturbing and minimum disturbance of the soil). The data corresponds to plots located at the Tausa municipality, one of the most important potato growing areas within the watershed. Though total C stocks in the surface layers seems to be similar between the tillage methods, at deeper layers a net increase was observed in the minimum tillage methods, suggesting that less oxidation of soil organic carbon is occurring in such layers as a consequence of reduced soil removal at harvest. The increased amounts of C found at lower levels in the soil profile may be an indication of migration of organic C from upper to lower layers. Higher Carbon contents in no till or minimum till systems have been extensively documented for a range of crops in temperate regions but much less information is available for tropical climates and virtually none exist for the high elevation Andean Paramos that have been converted into potato plantations.

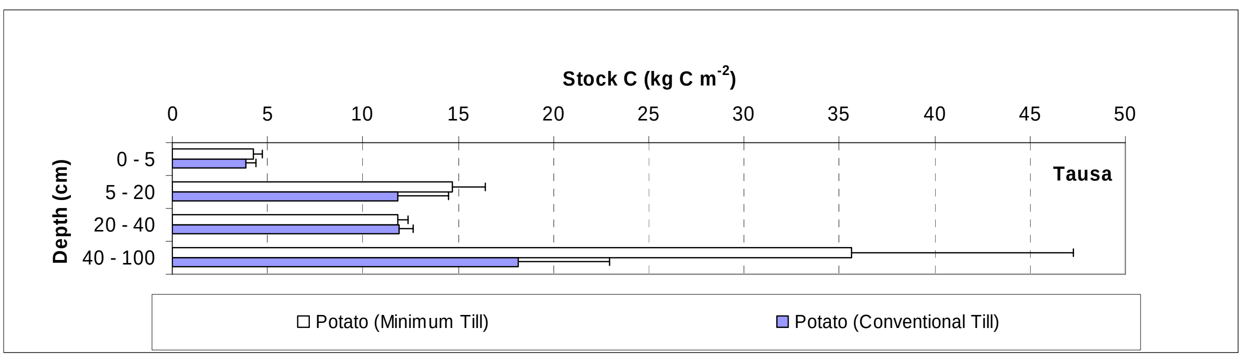

Figure 40. Total carbon stocks in the soil cultivated with potato under conventional and minimum tillage methods at the Tausa municipality, Fuquene watershed.

In Figure 41, we present a consolidated comparison of the dominant land use systems in the watershed and its average carbon stocks in soils. The native land uses (Paramo and mountain forest) consistently contain more carbon in the soil profile particularly at deeper layers. The conversion of native vegetation into pastures or crops has resulted in a significant net decrease in carbon stored in soils. A gross estimate indicates that some 50 to 80 Tg C could have been lost within the watershed due to land use change which has taken place predominantly during the last century. Conversion of forested land into highly productive pastures decreased C levels by almost 50%, while cropping potato also reduced the soil C stocks but to a lower extent. Once the native land is converted into other uses, a rapid process of land degradation is put in motion which usually results in the upper layers of the soil being lost by oxidation and erosion with drastic net losses of C from the land. The levels of Soil C in severely degraded pastures is only around 20% of the content in native land covers.

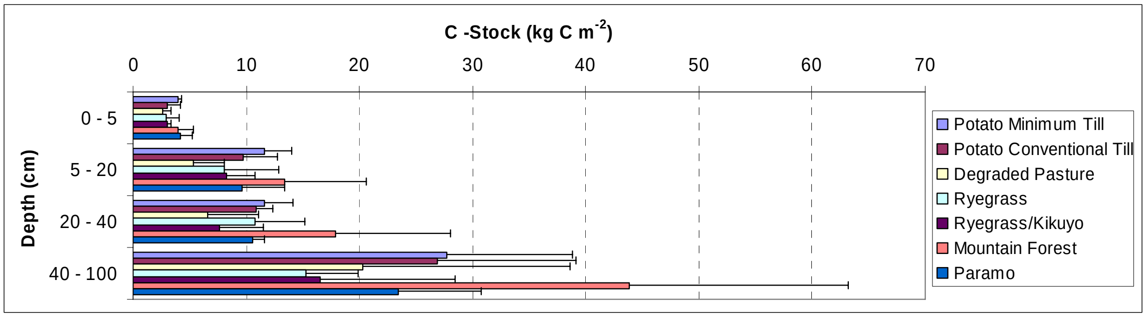

Figure 41. Total carbon stocks in the top 1 meter of soils under the main land use systems of the Fuquene watershed.

Fluxes of greenhouse gases: in Figures 42 and 43, net annual fluxes of methane and nitrous oxide from the dominant watershed land use systems are presented. Most of the land uses constitute an annual net sink for methane with the native land cover (Paramo and forest) being higher sinks. Potato under conventional tillage and Ryegrass pastures also constitute net sinks for methane but at a reduced rate as compared with the natural systems. The conversion from traditional to no till systems in potato results in the land being swuitched from a net sink into a small net source of this greenhouse gas into the atmosphere. Though precise reasons for this have not yet been evaluated, one possibility would be higher moisture content in soils under no tillage as a result of crop residue applications, which may increase the probability of the appearance of anaerobic microsites within the soil where methane is nerated. A further study is necessary to better explain the causes of this shift in function regarding methane oxidation.

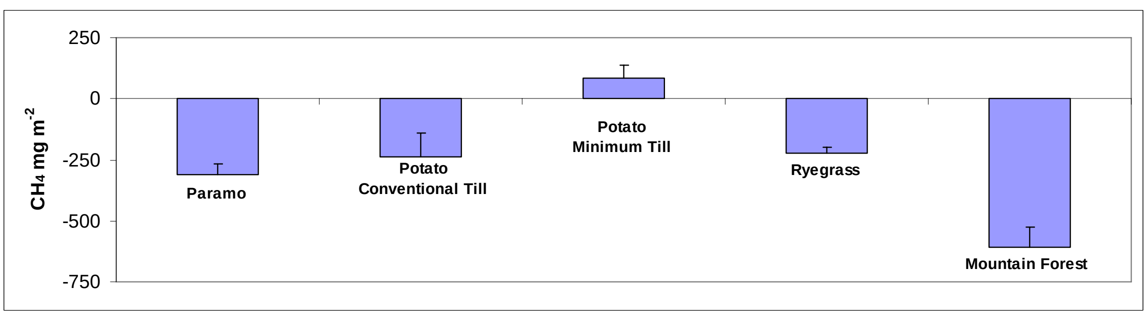

Figure 42. Net annual methane fluxes from the main land use systems in the Fuquene Watershed. Measurement period was August 2004 to July 2005.

As indicated in Figure 43, all land uses emit nitrous oxide into the atmosphere though at different rates: While the native land cover show low rates of emission due probably to low Nitrogen availability associated with low average annual temperatures in the soil (low mineralization rates), net emissions of N_2O increase significantly when fertilizer is applied to pastures and even more at higher doses of N application as used for potato plantations where as much as 300 kg N per year is applied in certain locations within the watershed. The higher emissions under no till potato compared to the traditional till methods was not anticipated because reduced soil disturbances should in principle result in lower N mineralization rates. Nevertheless if the incorporation of plant residues in the no till system favors the increase in soil moisture retention, this process can also result in more favorable conditions for denitrification. Annual losses of nitrogen due to nitrous oxide emission can account for 2-3% of the applied nitrogen, indicating that this environment fits within the high range of N_2O emissions per unit of applied fertilizer.

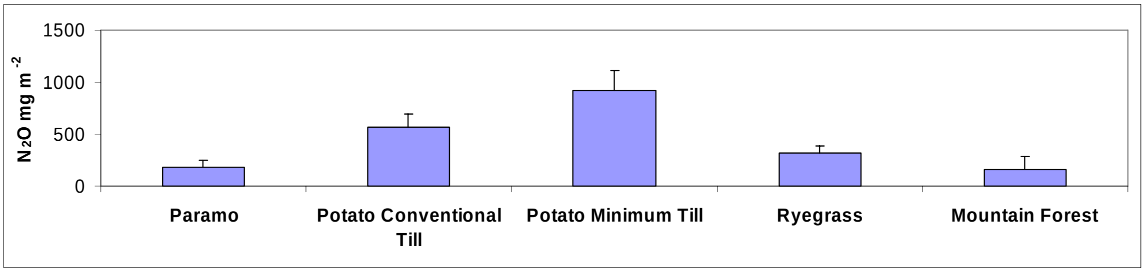

Figure 43. Net annual nitrous oxide fluxes from the main land use systems in the Fuquene Watershed. Measurement period was August 2004 to July 2005.

Integration of annual fluxes of both C and GHG will be done at the watershed level by using similar hydrologic response units and adding them using land cover data from remote sensing and GIS techniques. A Bayesian weight of evidence model is being used to extrapolate carbon stocks in soil as well as fluxes of other GHG to areas where no measurements were directly made in order to estimate total soil C stocks and overall GHG emissions at the watershed level. The overall global warming potential of different HUR will be calculated, and subsequently, a modeling process could be conducted to estimate how the reordering of land use systems in the watershed will influence the interaction with the environment. This analysis will provide valuable information in the analysis of tradeoffs between the provision of environmental services and the productive use of the land in the watershed. Policy makers could use the results from the studies being conducted at the watershed to take informed decisions on best alternatives to recuperate the functions of the watershed as provider of clean water to many rural areas al lower elevations.

Output target 2006

➢ ***Economic valuation of legume nodulating bacteria and soil structure carried out in at least five countries participating in the BGBD project.***

Work in progress

University of Agricultural Sciences/TSBF-CIAT, 2005. Proceedings of national Workshop on "Evolving Appropriate Methodologies for Economic Valuation of Ecosystem Services of Belowground Biodiversity", 12 -13th May 2005. UAS, Bangalore, India.
During the workshop methodological issues were discussed and a number of case studies were presented. Methodological issues included for example "social use values in the presence of negative externalities". A nice overview of conceptual and methodological issues was presented by Dr. B. V. Chinnappa Reddy. Case studies reported on related to the economic valuation of on-farm soil organic matter losses due to soil erosion in different agro-climatic zones of Karnataka, to the economic impact of striga as parasitic weed below the ground, or to the impact of sustainable agricultural production techniques on BGBD in rice cultivation. The last contribution at the workshop was on a topic of specific relevance to the BGBD project, namely agricultural intensification, ecological irreversibilities and BGBD.

A project publication on the economic valuation of rhizobium inoculation technology is in preparation by the Indonesian BGBD team.

Output target 2007

- ***Decision tools (GEOSOIL; Decision Tree) available for land use planning and targeting production systems in acid soil savannas***

Work in progress

Testing GEOSOIL for oil palm plantations

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TSBF-CIAT; CENIPALMA, Colombia

We worked together with CENIPALMA to systematize its soil data in a GIS-linked database and decision support tool for improving planning and decision making regarding the management of palm tree plantations. A consultancy to CENIPALMA project on "Characterization of Soils and Determination of Units of Agronomic Management in Oil Plantations of the Central Zone Palm of Colombia" was attended. The consultancy included a course of training in Basic Concepts of genesis, soil characteristics, sampling, soil improvement and evaluation of soils for oil palm plantation. Additionally, a training course on basic soil cartography geographical information systems, use of GPS and use of the popular MapMaker Program was made.

To socialize GEOSOIL, another training course for users on information entry and rescheduling of graphic for the visualization of the information was done. A qualified student of the National University of Colombia is applying Geosoil to obtain topographic maps, roads, rivers, etc. and thematic aspects in 29 farms. For each farm a customized evaluation was prepared. Manuals of MapMaker Program, a version of Geosoil Manual users and a technical bulletin to be used by SENA instructors were distributed. Results from this scaling up and out efforts will be reported next year.

Output target 2007

- ***Biophysical, social and policy niches in the landscape for targeting SLM technologies and enhanced ecosystem services identified and prioritized***

Completed work

Environmental impact of agricultural production practices in the savannas of northern Nigeria

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TSBF-CIAT, Nairobi, Kenya

The study highlights the salient agricultural production practices that impact on the environment in the savannas of northern Nigeria. Due to population pressure on land and the need to maintain household food supplies farmers have increased their land use intensity and natural resources extraction practices that degrade the environment. Some agricultural production practices were, however, found to be environmental friendly. The study recommends remedial measures that have to be taken to avert agricultural production practices that predispose farmers to practices and extractive activities that undermine the environment.

Socio-Economic Factors Influencing Intensity of Adoption of Fertilizer In The Semi-Arid Areas of Kenya: The Case Study Of Machakos District

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This study was to identify and explain the socio-economic factors which influence the intensity of fertilizer adoption in the semi-arid areas of Machakos district. Specific objectives included: to determine the socio-economic characteristics of farmers in the semi-arid areas of Machakos district; to identify the socio-economic characteristics which influence intensity of fertilizer adoption in the semi-arid areas of Machakos district and; to develop policy strategies for improving the intensity of adoption of fertilizer in the semi-arid areas of Kenya. We hypothesized that "Farmer socio-economic characteristics do not influence the intensity of fertilizer adoption".

According to the study, 45% of farmers adopted fertilizer (Table 37) while 82% adopted manure, the major type of manure being animal manure. Fertilizer adoption was therefore low hence the need for an improvement. The major reason cited for non-adoption of fertilizer was high cost of the input (Table 38). In terms of amounts, the study found out that farmers applied an average of 10.6 kg N ha^{-1} yr^{-1} and 19.3 kg P ha^{-1} yr^{-1} of fertilizer on maize, the major crop of the study area. Most of the farmers applied DAP only (42%) and, a combination of DAP and CAN (36%). This was however below the recommended levels.

Table 37. Adoption of fertilizer**.**

Variable	Category	Percent
Adoption of inorganic fertilizar	No	55
	Yes	45
Type of crop(s) fertilized	Maize only	67
	Maize and coffee	33
Fertilizer combination in the farm	DAP only	42
	CAN only	16
	NPK only	4
	DAP-CAN	36
	CAN-NPK	2

Source: Survey Results, 2005

Table 38. Reasons for non-adoption of inorganic fertilizer.

Factor	Percent
High cost of fertilizar	58
Lack of knowledge on its use	2
Fertilizar destroys the soil	11
Alternatives like manure are available	27
No crops are grown	2
Total	100

Source: Survey Results, 2005

Out of those who adopted manure, 57 % used animal manure, 28% used a combination of animal and compost manure, while 15% used compost manure. This indicates that most of the farmers in the semi-arid areas use animal manure. Farmers prefer using crop residues to feed livestock rather than make compost manure. In terms of amounts, farmers applied an average of 0.47 ton acre yr^{-1} (1.16 Mg ha^{-1} yr^{-1}) of manure on their crops. Farmers who did not adopt manure cited major reasons such as no livestock (61%), No means of transportation (17%) and manure buying is expensive.

A Tobit regression model was estimated and the results showed that seven out of eighteen factors included in the model were significant in influencing the intensity of adoption of fertilizer (Table 39). Off-farm employment, use of improved seeds, cash crop cultivation, agricultural extension and attendance to field days positively influenced the intensity of adoption of fertilizer, while family size and livestock ownership were negatively related with this phenomenon. The study recommended promotion of off-farm activities, improving the accessibility and effectiveness of extension services and reducing the cost of fertilizer as possible strategies for increasing the intensity of fertilizer adoption in the semi-arid areas of Kenya.

Table 39. Tobit regression for factors affecting the intensity of adoption of fertilizer

Variable	Coeff. (β)	Std.Err.	t-ratio	P-value
CONSTANT	-39.312	66.900	-0.588	0.557
AGE	0.801	1.105	0.725	0.469
Gender of the Household head	23.921	20.209	1.184	0.237
Education level	-3.339	2.959	-1.129	0.259
Family size	-8.298	6.173	-1.344	0.179$^{\#}$
No. of family members working on-farm	0.032	6.218	0.005	0.996
Whether family member works off-farm	43.898	22.478	1.953	0.051**
Total farm size	-3.412	2.953	-1.156	0.248
Total value of farm implements	0.000	0.001	0.247	0.805
Hired labour	25.053	23.154	1.082	0.279
Improved seeds	47.913	21.235	2.256	0.024**
Yield	0.412	0.735	0.561	0.575
Cultivation of Cash crop	58.178	25.256	2.304	0.021**
Value of livestock (Kshs)	-55.559	24.487	-2.269	0.023**
Distance to the nearest market	-4.440	5.122	-0.867	0.386
Access to credit by the farmer	-0.367	22.483	-0.016	0.987
Access to extension services	32.414	22.184	1.461	0.144$^{\#}$
Membership to a farmers group	4.326	23.621	0.183	0.855
Attendance to agricultural field days	38.364	19.839	1.934	0.053**

** $P\leq 0.05$, $^{\#}$.$P\leq 0.20$

Dependent Variable is amount of fertilizer applied/acre/y in kg

Log likelihood function - L (All variables)	= -272.278
Restricted Log likelihood function $-L_0$	= -297.300
Likelihood Ratio Index - LRI [1- (L/L_0)]	= 0.084
ANOVA based fit measure	= 0.411643
DECOMP based fit measure	= 0.412132

Source: Survey Results, 2005

The study recommended the following in order to increase the intensity of adoption of fertilizer in the semi-arid areas of Kenya:

- Promotion of off-farm employment activities especially small and medium enterprises by the Government and other stakeholders in the semi-arid areas, to augment income from farm activities. This can be done by establishing micro-credit programs in these areas and improving on the programs (i.e. ensuring accessibility and affordability of credit) where they are already in place.
- Improving the accessibility and effectiveness of agricultural extension services so as to disseminate information on improved soil fertility management practices especially the benefits of increased and optimal use of fertilizer. This can be done by increasing the number of extension staff and updating extension officers on new research findings. This will ensure that farmers make rational decisions while purchasing and applying fertilizer. Farmers should also be taught how to keep good farm records and evaluate the profitability of various enterprises to avoid allocation of economic resources to unprofitable enterprises.
- Reducing the cost of fertilizer. This can be done by improving the rural road infrastructure to reduce transportation costs and providing affordable credit to fertilizer traders to ensure adequate and timely availability of fertilizer to farmers.

Multiscale Analysis for Promoting Integrated Watershed Management

J. Rubiano[1], M. Quintero[1], R. D. Estrada[2] and A. Moreno[3]

[1]International Center for Tropical Agriculture (CIAT), A.A. 6713, Cali, Colombia; [2]Consortium for the Sustainable Development of the Andean Region (CONDESAN), A.A. 6713, Cali, Colombia; [3]Project "Cuencas Andinas" GTZ/CONDESAN, International Potato Center (CIP), PO Box 1558, Lima 12, Peru

The ongoing experience of a project implemented by the Consortium for the Sustainable Development of the Andean Region (CONDESAN) in the Fúquene watershed of Colombia is presented. Biophysical and socioeconomic knowledge is integrated in a complex process to offer sound solutions to a wider range of stakeholders affected by the eutrophication of Fúquene Lake. A multiscale analysis is carried out for every step of the process to warrant integrity in the use of information, inclusion and equity in the stakeholders' participation. The ultimate aim is to generate sustainable development processes in the rural sector. By focusing on the internalization of externalities derived from watershed management, transfers of funds from urban to rural populations are stimulated, triggering urban investments in rural environmental goods and services. The process starts integrating key spatial information, which is available at different scales for the site, in order to facilitate envisioning different land-use scenarios and their impacts upon water resources. Subsequently, selected alternative scenarios regarding the impact on the externalities identified are analyzed, using optimization models. Opportunities for and constraints to promoting cooperation among users are identified, using economic games in which more sustainable land-use or management alternatives are suggested. Strategic alliances and collective action are implemented in order to test the feasibility of environmental and economic alternatives. Their implementation is supported by co-funding schemes designed with private and public stakeholders having a role in the study area. Research needs and limitations of the methodology are discussed.

Watershed analysis to identify niches for sustainable land management and use: Altomayo (Peru) case study

M. Quintero[1], R. D. Estrada[2] and E. Girón[1]

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Collaborators: A. Moreno: Andean Watersheds Project (GTZ). International Potato Center (CIP) P.O. Box 1558, Lima 12, Peru; N. Paredes, C. Bonn, M. Gallardo: Proyecto Desarrollo Integral Alto Mayo. GTZ. Moyobamba-San Martín; F. Aspajo: Moyobamba Aqueduct Company. EPSA. Moyobamba, Peru.

In the transitional zone between the Andes and the Peruvian Amazon, the Mayo River watershed is located The basin is composed by several micro watersheds that supply water to various downstream urban aqueducts, rice irrigation systems and natural reserve areas. The native land cover has been disturbed by deforestation (4.2% yr^{-1}) and installation of coffee and pasture areas. Immigration (more than 50% of Moyobamba province population are immigrants) and favorable coffee prices in the market during the last years have contributed to accelerate natural landscape transformation. Miskiyacu is a micro watershed supplying drinking water to 40000 inhabitants of Moyobamba city. However, the replacement of native forest by farming uses seems to be causing the increment of suspended solids in water flows and therefore, water treatment cost has increased during the last years. During 2005, an environmental and socioeconomic watershed analysis of the Miskiyacu micro-watershed was conducted in order to provide guidelines for designing a mechanism of payment for environmental services (PES). The watershed analysis consisted in: 1) Hydrological modeling using SWAT (Soil & Water Assessment Tool), 2) Socioeconomic and environmental *ex ante* evaluation of land use and management scenarios, and 3) Determination of opportunity cost for implementing the proposed land use scenarios and valuation of environmental services.

For hydrological modeling, information about land cover, relief, soil map units and climatic data were used in order to determine the Hydrological Response Units of the Miskiyacu watershed. Thus, 28 HRU were identified. 8 HRU were prioritized based on the HRUs contribution to the environmental externalities (water flows and sediments) and land use change feasibility. The *ex ante* evaluation of land use and management scenarios was elaborated for the area covered by the prioritized HRUs. This analysis aimed to identify the better land use and management alternatives that provide multiple benefits: provision of environmental services (reduction of sediment yields), increment on rural income and labor employment. In addition, valuation of environmental services was achieved as an instrument to estimate the feasibility of implementing a PES by comparing the results with the values encountered in a previous study of willingness to pay by urban water users.

The evaluated scenarios were: coffee grown under shade, reforestation and live barriers in traditional production systems. The impacts of these potential scenarios were compared with the ones that would be caused if the traditional land use system is maintained (slash and burn – corn cropping – pastures). Installation of coffee under shade on areas currently exploited under the traditional land use system was the most appropriate land use scenario to be promoted by a PES mechanism according with the ex ante evaluation results, because of its multiple benefits. Although all potential scenarios produce less sediments (reduction of about 50%) than the traditional land use system, the coffee under shade scenario permits to increase farmers' income by 89% (Table 40). In contrast, reforestation and live barriers cause a reduction on net income of 5.3% and 9.7% respectively. However, while the traditional land use system requires an initial investment of $\$9^{-1}$ ha, the coffee under shade scenario needs an initial investment of \$176 ha^{-1}. The reforestation initial investment is \$470 ha^{-1}. In addition, the coffee under shade alternative is the only evaluated scenario by which labor employment is incremented (77% higher than the labor employed under the traditional land use system).

Table 40. Environmental and socioeconomic *ex ante* evaluation of distinct land use and management scenarios in the Miskiycau watershed (Peru) for a 10-year period.

	Traditional land use system: slash and burn – corn -pastures	Traditional land use system with live barriers	Coffee under shade on hillsides pasture lands	Reforestation on hillsides pasture lands
Net Income (US$)	76250	68802	144180	72187
Marginal income		-7748	44065	-27927
Initial cash investment (US$)	9	13	176	470
Sediment (t/ha)	21247	10623	11766	10620
Marginal sediments		-10624	-9481	-10627
Water yield (m^3)	2707711	2707711	2395627	2334858
Marginal water yield (m^3)			-312084	-372853
Labor employment	5682	5807.34	10071	5266
Marginal of labor employement		125	4389	-416

Regarding the design of a PES mechanism, the value of economic payments was determined for each scenario by calculating the cost of a ton of reduced sediments. Thus, one Mg of reduced sediments cost \$0.75 or \$35 ha^{-1} yr^{-1} for the live barriers scenario and is required to be paid every year in order to ensure the maintenance of the barriers. In another hand, for promoting shadow coffee is required to pay 1.31 Mg of sediments or \$53.6 ha^{-1} yr^{-1} during the first two years since this alternative only requires the initial investment as an incentive to replace the traditional land use.

In addition to the benefits or cost that can be caused by the land use scenarios and affect the farmers, there are other impacts that could affect the society. Through a value chain analysis considering the impacts on net incomes and labor employment, it was calculated that the coffee shadow scenario increase by 85% the social benefits while the live barriers and reforestation scenarios cause a reduction of 6.5% and 5.8% respectively (Table 40). The reduction of net income by the implementation of the live barriers scenario and the labor employment with reforestation explain these changes in percentages.

Given that the 7136 Moyobamba city families are willing to pay \$1.5 $month^{-1}$ as a contribution for promoting watershed resources conservation, it was calculated that it was only required two months of payments to cover the cost required for promoting coffee grown under shade in the HRU prioritized in the Miskiyacu micro watershed.

Validation of the Dahlem Desertification Paradigm in sub-humid tropics of Central America

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A land degradation workshop was held in Honduras, 14-19 November 2005. This meeting was hosted by the MIS (Manejo Integrado de Suelos) Consortium, as part of collaborative activities with the ARID*net*, a collaborative research network working on land desertification that is supported by the National Science Foundation. The workshop was designed to bring together a variety of natural and social scientists from different countries to extend and expand the development and application of the *Dahlem Desertification Paradigm to* land degradation and recovery of steepland agricultural systems in Central America, including an assessment of the unique "Quesungual" slash and mulch agroforestry system. The DDP is a flexible and synthetic framework to address desertification problems. It recognizes the simultaneous roles of the biophysical and socioeconomic factors in the land degradation process and proposes the identification of key variables and thresholds to more effectively prioritise policy and management interventions.

The workshop addressed three specific objectives. The first was to complete a DDP-based analysis of the opportunities for and limitations to the recovery of an agroecological system in the Guarita municipality, and the potential application of the Quesungual slash and mulch agroforestry system. The second objective was to complete a DDP-based analysis of the development and application QSMAS in the Candelaria municipality. The third objective was to contribute to the continuing evolution of the DDP by developing recommendations for how it might be more effectively applied to land degradation in the seasonally dry tropics.

Participants (Photo 1) visited the two municipalities and interviewed farmers, local organizations and government representatives. Based on information collected several conceptual models were developed as a preliminary step for the application of the DDP framework. Figure 44 shows one of the models developed to understand the main factors associated with the development of the Quesungual.

Photo 1. Participants of the workshop.

The full report is under preparation. However, preliminary results of the analysis indicate that the Quesungual system is a result of a unique balance between production, conservation, food security and income generation. This balance has been driven by several "slow" biophysical and socio-economic variables. We plan to synthesize and submit the results of the workshop to a peer-reviewed international journal and disseminate the results through the MIS and AridNet network.

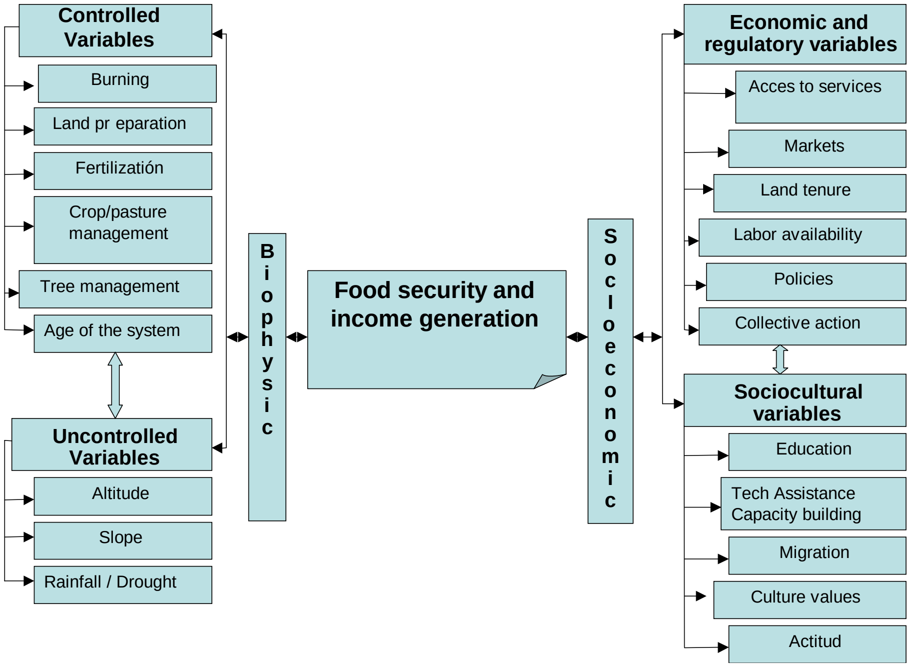

Figure 44. Biophysical and socieconomic factors influencing the development of the Quesungual system.

Output target 2008

- ***Methods for socio-cultural and economic valuation of ecosystem services developed and applied for trade-off and policy analysis used in at least in 2 humid and 2 sub-humid agroecological zones***

Completed work

Model of optimization for ex-ante evaluation of land use alternatives and measurement of environmental externalities (ECOSAUT)

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A multicriteria optimization model was designed for the ex-ante analysis, by means of which optimal values of the decision variables that maximize or minimize watershed management objectives can be identified without violating imposed constraints. Linear programming has been applied successfully to measure the tradeoffs between the economic performance of different activities and the environmental externalities. The Payment for Environmental Services (PES) Project - (CONDESAN, GTZ and CPWF) uses these models to support stakeholders in making decisions about multiple land-use options. It is difficult to find alternatives with complementarities related to the generation of jobs, profitability, environmental conservation and social equity, all at the same time. Thus, the constraints or variables used in the optimization model correspond to the restrictions given by the biological and economic capacities of the system, farmers' considerations, and/or local and regional policies. The decision alternatives refer to the activities (individual or collective) that can exist at the HRU or watershed level and have a relationship with the constraints (Table 41). The biophysical constraints included in the model are the quantity of water, sediments and N and P in the water flows that are affected by land use. The socioeconomic constraints are availability of labor, productive land, levels of income and wealth.

With the use of this model, socioeconomic and environmental constraints are then considered to identify feasible land-use changes. Thus the multiscale biophysical and socioeconomic constraints are integrated in a modeled agroecological system to determine the impact on farmers' net income and environmental externalities caused by land-use and management alternatives. The optimization model calculates the costs of changes in land use and technology under different spatial and temporal scenarios. Optimal solutions are the byproduct of trade-off analyses among stakeholders and satisfaction of multiple constraints. The optimization exercise evaluates *ex-ante* the economic and social potential of the alternatives in improving the quality of life, and the results can stimulate private and official investors to fund some of the alternatives.

By using the optimization model, acceptable values for decision variables and optimal income thresholds (e.g. land uses, sales of agricultural products and services, loans) are identified and adjusted to an acceptable level of environmental impact. Sensitivity analysis provides quantitative information regarding the value of the imposed environmental and socioeconomic constraints; in other words, the shadow price. Shadow prices are useful for determining the price of services and goods that do not have a market price (production of sediments, water flows, etc). This value is equal to the reduction in net income when the system has to be adjusted to reduce one unit of the negative externality. The magnitude of the shadow price depends on farmers' socioeconomic and biophysical conditions. Thus the shadow prices will correspond to the value of resources, which is critical to the externalities issue covered by the PES project. It is not related, for example, to the total amount of soil N and P, but to the quantity that moves across boundaries, the value of that N and P downstream right into Fúquene Lake and surrounding towns, and the value of the reduction of the externality by its source.

Table 41. Principal variables and decision alternatives in the ECOSAUT model.

VARIABLES[1]	DECISION ALTERNATIVES SCENARIOS									
	Rotations of crops (ha yr^{-1}) with/without minimum tillage & green manures	Permanent forests (ha)	Permanent pastures with/without green manures	Feed concentrates for cattle production (Mg yr^{-1})	No. cows	Farm incomes (sales of meat, milk, wood, harvest) (Mg yr^{-1})	Environmental incomes for environmental services provided: water (cm^3 yr^{-1}) and CO2 (Mg yr^{-1})	N and P pollution residual waters (Mg yr^{-1})	Buys & sells of labor according to job profiles	Bank loans
Net incomes (per period simulated) (objective function)	X	X	X	X	X	X	X		X	X
Capital	X	X	X	X	X					X
Cash flows (by yr)	X	X	X	X	X	X	X		X	
Land availability (upper, medium and downstream watershed) (ha)	X	X	X							
Erosion thresholds by land use (Mg yr^{-1})	X	X	X							
Hydrological balance, contribution to the superficial aquifer (cm^3 ha^{-1} yr^{-1})	X	X	X		X		X			
N contributed to water flows by land uses (Mg ha-1 yr-1)	X	X	X	X	X			X		
CO_2 fixation by vegetative cover (Mg ha^{-1} yr^{-1})	X	X	X							
Labor profiles by land uses (no. Work days yr^{-1})	X	X	X						X	
Wood production by planted forests (Mg ha^{-1})		X								
Wood production by native forests (Mg ha^{-1})		X								
1Energy production for livestock (Megacal K^{-1} ha^{-1})	X		X	X	X					
Protein production for livestock (Kg dry matter Ha^{-1})	X		X	X	X					
Dairy production (Mg yr^{-1})					X					
Meat production (Mg yr^{-1})					X	X				

[1] X indicates the presence of a relationship between an alternative and a variable.

In summary, ECOSAUT is a model created for:

- Representing agro-ecological systems and relate it with natural resource management issues, to find out solution alternatives for problems that are often complex.
- Conducting *ex-ante* impact assessment of land use changes in a given watershed.
- Conducting *ex-ante* impact assessment for long-term periods because changes in environmental externalities are related with gradual biophysical processes such erosion, changes in soil properties, eutrophication, etc.
- Integrating environmental and socioeconomic variables to evaluate alternatives according with the environmental and socioeconomic impact (environmental services, income and employment).
- Distinguishing which is the variables state that describes the performance of the system. For example the magnitude of environmental externalities (water yield, sedimentation, etc) that could indicate the environmental impact of local actions on the society.
- Ex post impact assessment when selected land use alternatives are implemented.
- Carrying out trade off analysis to determine if variables are competitive, substitutive or complementary due to possible shared impact on the maximized function (incomes, employment, etc).
- Providing quantitative information (shadow prices) about how important are system constraints during economic maximization and environmental impact minimization.
- Determining the value of environmental externalities through shadow prices, if modeling has considered economic cost and benefits of evaluated alternatives.

This model and approach are being used in the analysis of the five pilot Andean watersheds (Colombia, Ecuador, Peru and Bolivia) in order to support the identification of land use alternatives and management practices for production systems to allow the internalization of externalities. The main externalities that are subject of analysis and interventions are sedimentation, water pollution, and decrease of water yield in dry seasons and carbon sequestration.

Work in progress

Rehabilitation of degraded lands through silvopastoral systems and reforestation of marginal lands in the Caribbean savannas of Colombia. MDL project to use carbon trading for pasture rehabilitation and sustainable development

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Land degradation in the tropical savannas of northern Colombia has advanced dramatically in the last decades as a consequence on improper cattle ranching and strong droughts that have been exacerbated recently. Rehabilitate the productivity of pastures is a major concern for farmers, local and regional authorities. This project aims to enhance the productivity and natural resource base of 2,000 hectares of degraded lands by fostering the improved use of agricultural and tree material, notably through the expanded use of a silvopastoral system developed by the Colombian National Agricultural Research Organization (CORPOICA). This system consists in the planting of forage shrubs very well adapted to the region (*Gliricydia sepium*, *Cresentia Cujete* and *Leucaena leucocephala*) with high-value timber species (*Pachira quinata*, *Switenia macrophylla* and *Tabebuia rosea*). The original degraded pastures are recuperated using improved grasses, fertilizer application and other interventions to correct soil compaction. In the vast areas where land degradation has advanced to a severe grade, the project will implement reforestation using native tree species (*Albizia saman*, *Guazuma ulmifolia*, *Anacardium excelsum*, *Tabebuia billbergii*, etc.). In this case grasses will also be established in the soils most devoid of vegetation, to favor rapid land cover, minimize erosion, and accelerate the rebuild of soil organic matter. Priority in reforestation will be given to areas surrounding water streams and undulating terrain where soil erosion is a major problem. External resources will be employed to cover up-front costs linked to the establishment of the system and that exceed the capability of local producers to allow its expansion at a significant enough rate to slow the process of land degradation. The project expects to cover 200-400 farms in the region surrounding Monteria.

The project is expected to sequester 0.17 Gg CO_2e (CO_2 equivalents) by 2012 and 0.38 Gg CO_2e by 2017. Total carbon accumulation of 23 Mg CO_2 equivalents per hectare per year could be obtained in the reforestation sites given the high tree number per unit area used for the reforestation (tree cover will reach 60% in the fourth year and 90% in year 10). The improved management will increase the storage of carbon both above- and below-ground. The recovery of the degraded land and reestablishment of a grass and tree cover will favor biodiversity and will reduce erosion, triggering in turn other environmental benefits. Rural communities living of small scale livestock production will benefit through an increase in their income and in the sustainability of their livelihood (currently threatened by land degradation). Local residents will also enjoy social benefits through the creation of direct employment for the tree nurseries, planting operations, fencing and maintenance of the established silvopastoral and reforestation systems. The local economy will be stimulated by the increased resources being injected in the economy through the project implementation and especially through higher productivity. Local and regional institutions including academic bodies will benefit from capacity building in topics related to CDM projects and silvopastoral systems. The activities proposed will not change land ownership and are not expected to result in leakage outside the project boundaries. The additional income from carbon sequestration will be key for the development of the activities, while the increase in income they will generate will clearly increase the incentive of farmers to keep them permanently.

The project is developed by Centro Internacional de Agricultura Tropical (CIAT), and the Colombian National Agricultural Research Organization (CORPOICA), and the Environmental Corporation of the Sinu And San Jorge Rivers (CVS) The project has been successfully negotiated with the BIOCARBON Fund as a CDM project and will be the first of this type to be implemented in Colombia. Farmers have been already selected and organized in an association of producers and the project operations in the field will start towards the end of 2006. Transaction costs of this project will be carefully assessed to help in the identification of suitable MDL projects in Latin America to be promoted as CDM activities.

Output target 2008

- ***In at least four of the countries participating in the BGBD project, policy stimulated to include matters related to BGBD management, and sustainable utilization***

Work in progress

This activity will commence during phase II of the CSM-BGBD project and work will commence in 2007 to achieve this output target. Individual scientists studying different BGBD species will determine the species loss in any niche and country synthesis to determine species richness and /or loss of richness per land use, niche or management type and present the findings in reports and published papers. Quantitative analyses will be carried out on the link between land use intensity and BGBD and from the analysis; it will be possible to relate land use intensity and other variables to BGBD loss. Socio-economic scientists in each participating country together with the GCO socio-cultural consultant and natural resource economics consultant will analyse jointly with the country scientists and prioritize thematic areas to be addressed by the project in order to achieve maximum benefits and impacts of the project outcomes before embarking on phase two implementation in 2006. Each of the partner countries will in a participatory process with conservationists, communities and farmers identify thematic problem areas to be addressed and collective joint action select demonstration sites. Each partner countries will engage a policy analyst to study and highlight BGBD policy gaps and thereafter find mechanisms of involving policy makers and politicians in the process so that the identified gaps and/or areas are addressed.

Progress towards achieving output level outcome

- *Principles of sustainable land management integrated in country policies and programs*

This output is aimed at restoring degraded agroecosystems to economic and ecologic productivity, while recovering the function of such lands as providers of a range of ecosystem goods and services. Tools developed over the past few years are starting to be used by farmer associations to better plan the use of their land. An example of that is the use of GEOSOIL decision support system for planning oil palm in the acid soil savannas of Colombia. During 2005, important advances were made towards the development and testing of methods for assessing and putting value on environmental services, particularly at the Fuquene Watershed in the Colombian Andes. Intensive field monitoring coupled to the use of special software allowed to identify the most suitable options at the watershed scale to balance productivity and socioeconomic profitability and the maintenance of ecosystem functions. Methods will be refined in 2006 to include the potential to generate tradable Carbon in the watershed and how this could facilitate the adoption of desirable land use management practices. The use of similar approaches allowed to define that shaded coffee is the most suitable land use option for farmers in the Altomayo Watershed in Peru to provide not only income and job generation, but also reduced impact on the environment. In a contrasting drier agroecosystem, the steepland region of Lempira in Honduras, significant advances were made towards understanding the drivers behind the adoption of the Quesungual slash and mulch agroforestry system. This knowledge is already being used to promote the expansion of the systems into an even drier region in Nicaragua. The potential of two key ecosystems in Latin America, the Amazon rainforest and the acid soil savannas, to serve as net sinks for atmospheric carbon and to play a role in mitigating climate change, was assessed.

The interactions between the policy environment and the socio-cultural and economic condition have been addressed through studies that look for enabling environments. By this the support systems are meant to address financial and technological infrastructure as well as the extension services for scaling out win-win land use and management alternatives. Research showed that specific strategic alliances are required for the poorest farmers to benefit from financial mechanism that would allow them to adopt new technologies.

Progress towards achieving output level impact

- *Reversing land degradation contribute to global SLM priorities and goals*

A special project to rehabilitate extensive areas of degraded lands in the Caribbean savannas from Colombia through the use of silvopastoral systems and reforestation with native species was successfully negotiated with the Biocarbon Fund. This is the first initiative to use Carbon trading to cover part of the cost of the actions required to stop and reverse land degradation. Though this is a long term initiative, expected impact on the livelihoods of poor rural communities, including native Indians is very high. Outcomes from the special projects mentioned above are helping to set the scene for the articulation of future plans for payment of environmental services in rural areas. Governments, particularly in Latin America could use the outcomes of such initiatives to define policies to reverse land degradation at local and regional levels. With the partnership of a large interdisciplinary team, CONDESAN is aiming to provide local and regional authorities with guidelines to help policy makers in the definition of incentives and mechanisms to include payment from environmental services as part of the local land use planning.

ANNEX –1: LIST OF STAFF

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Osgood, Diane (Economist, BGBD Project)
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Njenga, Francis (Laboratory Attendant)
Muranganwa, Francis (Field Worker Harare)

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Akech, Caren (Secretary)
Akuro, Elly (Driver/Field Assistant)
Chisvino, Stephen (Driver/OA, Harare)
Kareri, Alice (Administrator)
Meyo, Rosemary (Administrative Assistant)
Mulogoli, Caleb (Finance/IT Asst)
Ngutu, Charles (Finance/Admin. Officer)
Nyamhingura, Isabella (Admin. Asst, Harare)
Ogola, Juliet (Senior Administrative Secretary)

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Rao, Idupulapati (Plant Nutrition and Physiology) (40% TSBF Institute, 30% IP1, 30% IP5)
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Molina, Diego Luis
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ANNEX-2: LIST OF STUDENTS

A. TSBF Institute - Africa

Name	Nationality	Degree	Status	Institution	Research theme
Alejandro Ponce		PhD	Continuing	CINVESTAV-IPN	Abundance and diversity of macrofauna and soil aggregates in soil of Central Kenya added with organic material.
Aliou Faye	Senegalese	PhD		Centre International d'Enseignement a Distance, Rouen, France	Contribution of the assessment of the rhizobial diversity and its impact on the soil fertility within a natural settlement of *Acacia nilotica* subs *tomentosa*: example of the natural forest of Diarra located in the Senegal River Valley.
Amadou Sarr	Mauritanian	PhD	Completed	University Cadi Ayyad, Faculte des Sciences, Semlalia/ arrakech (Maroc).	Symbiotic improvement of growth of *Acacia senegal* and *Acacia nilotica* in Senegal and Mauritania.
Charles Walaga	Ugandan	PhD	Continuing	University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria	Organic agriculture development and livelihood improvement in Uganda: Future scenarios and policy measures.
Dilys Kpongor	Ghanaian	PhD	Continuing	ZEF, Univ. of Bonn, Germany	Evaluation of the best-bet soil fertility restoration technologies in Northern Nigeria.
Edward Yeboah	Ghanaian	PhD	Continuing	University of Ghana, Ghana	Sustaining crop productivity: the influence of organic resource quality and quantity.
Elisabeth Gotschi	Austrian	PhD	Continuing	University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria	Social capital in smallholder marketing groups in Sofala Province, Mozambique.
Jacintha Kimiti	Kenyan	PhD	Continuing	Kenyatta University, Kenya	Integrating legumes in the farming systems of Eastern Kenya to enhance soil fertility.
Jackson Tumwine	Ugandan	PhD	Continuing	University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria	Linking farmers to market: challenges and opportunities of improving rural livelihoods for communities affected by HIV/AIDS in Uganda.

Name	Nationality	Degree	Status	Institution	Research theme
Jane Kapkiyai	Kenyan	PhD	Continuing	Cornell University, USA	Effects of legume green manures on crop productivity and nutrient cycling in maize-based cropping systems of Western Kenya.
John Ojiem	Kenyan	PhD	Continuing	Wageningen University, Netherlands	Niche-based approach to soil fertility improvement by legumes in Western Kenya smallholder farming systems.
Joseph Kimetu	Kenyan	PhD	Continuing	Cornell University, USA	Restoration of soils in Western Kenya using manure and *Tithonia diversifolia*.
Juan Cobo	Colombian	PhD	Continuing	Hohenheim, Germany	Spatial and temporal management of nutrient and water resources in Zimbabwe and Mozambique.
Kibiby Mtenga	Tanzanian	PhD	Continuing	Cornell University, USA	Gender and soil fertility management in Malawi: a participatory analysis of farmers' incentives to reinvest in soil fertility management innovations by women and men farmers.
Michael Misiko	Kenyan	PhD	Continuing	Wageningen University, Netherlands	Knowledge and networks: Challenges and opportunities for scaling up integrated soil fertility management regimes.
Monicah Mucheru	Kenyan	PhD	Continuing	Kenyatta University, Kenya	N dynamics as affected by soil fertility status and nutrient replenishment inputs in the central highlands of Kenya.
Pablo Tittonell	Argentina	PhD	Continuing	Wageningen University, Netherlands	Exploring options, analysing tradeoffs and deriving indicators of efficiency for integrated nutrient management in smallholder farming systems of East Africa.
Pamela Pali	Ugandan	PhD	Continuing	University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria	Impact of organic agriculture in Uganda: improving livelihoods through sustainable natural resource management.
Pauline Nhamo	Zimbabwean	PhD	Continuing	University of California, USA	Exploring how organic and mineral nutrient combinations interact to regulate nutrient cycling.

Name	Nationality	Degree	Status	Institution	Research theme
Peter Ebanyat	Ugandan	PhD	Continuing	Wageningen University, Netherlands	Dynamics of soil organic matter and nitrogen in farmer field schools generated integrated soil fertility management practices.
S. Some	Burkinabe	PhD		ZEF, Univ. of Bonn, Germany	Water use efficiency of sorghum based cropping systems in Dano, Burkina Faso.
Shamie Zingore	Zimbabwean	PhD	Continuing	Wageningen University, Netherlands	Farm-scale evaluation of nutrient use efficiencies of resource management options in smallholder farming systems of Zimbabwe.
Agnes Kavoo	Kenyan	MSc	Continuing	Kenyatta University, Kenya	Interactions between resource quality, aggregate turnover, and C and N cycling in the Central Highlands of Kenya.
Dick Lufafa	Ugandan	MSc	Continuing	Makerere University, Uganda	On-farm comparison of the economic profitability of selected dual-purpose live barriers. Second year.
Emily Ruto	Kenyan	MSc	Completed	Moi University	An attempt to promote the use of prep-pac in Western Kenya.
Esther Rutto	Kenyan	MSc	Completed	Egerton University, Kenya	Farmers' perceptions and evaluation of integrated approaches to combat striga, stemborer and soil fertility problems in Western Kenya.
Giannis Papanagiotou	Greek	MSc	Continuing	Wageningen University, Netherlands	The effect of endogeic earthworms on aggregate formation, stability and carbon distribution within different aggregate fragments in a vitro study.
Grace Agwaru	Ugandan	MSc	Continuing	Makerere University, Uganda	Assessing approaches and developing methods for presentation of research results to farmers within their livelihood situations: a case study in Soroti and Arua Districts.
Harrison Githinji	Kenyan	MSc	Continuing	Moi University	Effects of conservation tillage and organic residues on crop productivity.
Job Ogada	Kenyan		Completed	Egerton University, Kenya	Evaluation of interactions between farmers' resource endowment and within-farm resource flows in Western Kenya.

Name	Nationality	Degree	Status	Institution	Research theme
Judith Odhiambo	Kenyan		Continuing	Egerton University, Kenya	Effect of selected legume species on germination of *Striga hermonthica* seeds: a control strategy in maize.
Justin Muriuki	Kenyan	MSc	Continuing	Kenyatta University, Kenya	Economic evaluation of organic and inorganic technologies for soil nutrient enhancement in Mukuuni and Murugi, Central Kenya.
Kiwanka Achilles	Ugandan	MSc	Continuing	Makerere University, Uganda	Environmental and socio-economic impact of organic farming on the livelihood of small-scale farmers in Uganda.
Mary Baaru	Kenyan	MSc	Completed	Kenyatta University, Kenya	Effects of organic materials of differing quality and inorganic fertilizer on soil microbial biomass at Kabete, Kenya.
Matieu Henry	French	MSc	Continuing	CNEARC/ ENGREF	Carbon sequestration in the agrarian system of Western Kenya and eligibility to clean development mechanism.
Micheal Ochieng	Kenyan	MSc	Continuing	Jomo Kenyatta University, Kenya	On-farm interaction between soil fertility factors, farmer management, pests and diseases and the growth and yields of banana in Maragwa district, Kenya.
Moses Thuita	Kenyan	MSc	Completed	Moi University	On farm testing of phosphorus availability from phosphate rocks as affected by addition of local organic resources in western Kenya.
Mwashasha Rashidi	Kenyan	MSc	Continuing	Jomo Kenyatta, Kenya	Evaluation of the potential of various AMF strains to improve the initial growth of banana.
Nekesa Abigail	Kenyan	MSc	Completed	Moi University	A study on the liming effect of Minjingu phosphate rock in an acidic soil in western Kenya.
Nelson Ojango	Kenyan	MSc	Completed	Wye College, University of London, UK	Market and demand for soybean by livestock feed industries in Kenya.
Salome Muriuki	Kenyan	MSc	Completed	Kenyatta University, Kenya	Assement of long term impacts of organic and inorganic fertilizers on soil P franctions in Machanga, Mbeere District, Kenya.

Name	Nationality	Degree	Status	Institution	Research theme
Telesphoret Ndabamenya	Rwandese	MSc	Continuing	Wageningen University, Netherlands	Interactions of soil macrofauna, tillage and organic amendment affect soil aggregation, organic matter dynamics and crop performance in Kenyan cropping systems.
Wouter Ton	Dutch	MSc	Completed	University Twente, Netherlands	Comparison of participatory approaches in Uganda.
Samwel Njoroge	Kenyan	BSc	Completed	Kenyatta University, Kenya	Laboratory methods for soil analysis.
Amek Tom	Kenyan	MA	Continuing	Economics Department, University of Nairobi, Kenya	Ex-ante adoption potential of seven technological options for improving ecosystem services in Kenya.
Lucy Njaramba	Kenyan	MA	Continuing	Institute of Development Studies (IDS), University of Nairobi, Kenya	Market and demand for soybean by food processing industries and supermarkets in Kenya.

B. TSBF Institute - Latin America

Name	Nationality	Degree	Status	Institution	Research theme
Alvaro Rincón	Colombian	PhD	Completed	National University, Colombia	Integration of maize with forages to recuperate degraded pastures in the Llanos of Colombia.
Andrés Rangel	Colombian	PhD	Continuing	University of Hannover, Germany	Mechanisms of aluminum resistance in common bean.
Annabé Louw-Gaume	South African	PhD	Continuing	ETHZ, Zurich	Mechanisms of low phosphorus adaptation in *Brachiaria*.
Aracely Castro	Honduran	PhD	Continuing	Nacional University, Colombia	Nutrient dynamics in the Quesungual Agroforestry System.
Edier Humberto Pérez	Colombian	PhD	Continuing	U. del Valle, Colombia	Pollutants and soil water fluxes.
Jorge F. Navia	Colombian	PhD	Continuing	National University, Colombia	Impact of residue quality on beneficial soil biota in root-rot infested soils.
Julie Major	Canadian	PhD	Continuing	Cornell University, USA	Reducing nutrient leaching on acid soils trough charcoal amendments to soils.
Mariela Rivera P.	Colombian	PhD	Continuing	Nacional University, Colombia	Water dynamics in the Quesungual Agroforestry System.

Name	Nationality	Degree	Status	Institution	Research theme
Martha Bolaños	Colombian	PhD	Completed	National University, Colombia	Role of soil enzymes in vegetable banana production systems.
Natasha Pauli	Australian	PhD	Continuing	Univ. of Western Australia	The potential of the Quesungual Agroforestry System for soil biodiversity conservation and management in Western Honduras.
Nelson Castañeda	Colombian	PhD	Continuing	University of Goettingen, Germany	Genotypic variation in P acquisition & utilization in *A. pintoi.*
Sergio Mejía	Colombian	PhD	Continuing	National University, Colombia	Identification of candidate genes responsible for adaptation of tropical forage grass, *Brachiaria* to low phosphorus soils.
Steve Fonte	American	PhD	Continuing	U.C.Davis, USA	Influence of management practices, litter inputs and earthworm activity on soil fertility and soil organic matter dynamics in the Quesungual Agroforestry System.
Twaha Atenyi	Ugandan	PhD	Completed	Agricultural University of Norway	Soil phosphorus transformations and organic matter dynamics.
Belisario Volverás	Colombian	MSc	Continuing	U.de Nariño, Pasto-Colombia	No-tillage systems in hillsides planted with potato.
José Jaumer Ricaurte	Colombian	MSc	Continuing	National University, Colombia	Impact of aluminium tolerant *Brachiaria* genotypes on soil quality characteristics of an Oxisol of the Altillanura of the Meta Department of Colombia.
Jesús H. Galvis	Colombian	MSc	Completed	National University, Colombia	Sealing and crusting in the Llanos.
José Augusto Rodríguez T.	Colombian	MSc	Completed	National University, Colombia	Influence of some a amendments in some physical, chemical and biological characteristics of a magnesium soils.
Luis Carlos Pardo	Colombian	MSc	Completed	Universidad del Valle, Cali	Biological erosion in rainforest.
Lyda Zárate	Colombian	MSc	Completed	National University, Colombia	Dynamics of water stable soil aggregation mediated by three different AMF species.

Name	Nationality	Degree	Status	Institution	Research theme
Marcela Quintero	Colombian	MSc	Continuing	University of Florida	Measurement and valuation of soil environmental services in the Andes.
Oscar Iván Ferreira	Honduran	MSc	Continuing	Nacional University, Colombia	Balances of greenhouse gases in the Quesungual system.
Oscar Molina	Colombian	MSc	Completed	National University, Colombia	Effect of residual P fertilizer and organic manure application on mycorrhizal association of maize-bean rotation in P-fixing Andisol in Cauca, Colombia.
Agustina Calero	Nicaragua	BSc	Completed	UNA	Physiography of the Rio la Danta microwatershed, Somotillo, Nicaragua.
Andrés Ceballos and Victor Bermúdez	Colombian	BSc	Continuing	Universidad del Valle, Cali-Colombia	Charcoal production by small scale producers in Colombia: improvements on the efficiency of production and and on safetty production.
Andrés Pereira Abella	Colombian	BSc	Continuing	Universidad del Valle, Cali-Colombia	Comparison of NIRS vs MIRS methodologies for analysis of total soil carbon and nitrogen.
Denis Valladares	Honduras	BSc	Completed	ESNACIFOR	
Gettsy Elizabeth Quiñónez Mora	Colombian	BSc	Continuing	Universidad del Valle, Cali-Colombia	Estimating total carbon stocks in soils from the Fuquene Lagoon watershed using a Bayesian statistical model.
Joisse Rincón	Colombian	BSc	Completed	National University, Colombia	Drought adaptation in *Brachiaria*.
José S. Muñoz	Colombian	BSc	Completed	National University, Colombia	Composting in Pescador, Cauca: an appropriate technology for residue management and environmental protection.
Leslie Fariña	Nicaragua	BSc	Completed	UNA	Physiography of the Rio la Danta microwatershed, Somotillo, Nicaragua.
Lester Talley	Nicaragua	BSc	Completed	UNA	Floristic characterization of the Rio la Danta microwatershed, Somotillo, Nicaragua.
Lina M. Gaviria	Colombian	BSc	Completed	U. Surcolombiana, Neiva-Colombia	Characterization of surface biogenic structures under different cassava treatments in Santander de Quilichao.

Name	Nationality	Degree	Status	Institution	Research theme
Luisa Jiménez	Colombian	BSc	Continuing	National University, Colombia	Physicochemical characterization of charcoal for agricultural use.
Milton Delcid	Honduras	BSc	Completed	UNA	Nitrogen response curves to validate the NuMaSS system.
Namán Sánchez	Honduras	BSc	Completed	ESNACIFOR	Biomass accumulation and nutrient composition of three forest species in the Quesungual system.
Osman Contreras	Honduras	BSc	Completed	UNA	Nitrogen response curves to validate the NuMaSS system.
Tomás Gutiérrez	Nicaragua	BSc	Completed	UNA	Floristic characterization of the Rio la Danta microwatershed, Somotillo, Nicaragua.
Yenni López	Colombian	BSc	Completed	National University, Colombia	Drought adaptation in common bean.

ANNEX-3: LIST OF PARTNERS

TSBF Institute's research for development programme is implemented through projects implemented with a wide range of partners. These include in particular the scientists from NARES and universities in tropical countries and advanced research institutes and universities in developed countries, who are members of the programme networks, of which the largest is the African Network for Soil Biology and Fertility (AfNet) followed by MIS and SARNet. Other projects are implemented through CGIAR system-wide programmes (SWPs) such as AHI and Challenge Programme. Donors for TSBF projects currently include, in addition to the Rockefeller Foundation, CIDA, IDRC, DIFD, IFAD, DANIDA, BMZ, NORAD, USAID, ACIAR and UNEP-GEF and the consortia of donors to the CGIAR's SWPs and CPs. Some of these projects fund the TSBF-CIAT outposted staff in Zimbabwe, Uganda and Honduras.

At the regional basis TSBF-CIAT's alliance with ICRAF and the NARS in East and Southern Africa will be expanded to ICRISAT and CIMMYT and possibly to IITA and WARDA in West Africa. Cooperation with FARA and other regional organization such as ASARECA, CORAF and SACCAR will be strengthened. In Latin America work will focus in Central American hillsides with the MIS consortium, in the Andean hillsides region with CONDESAN and CORPOICA and in the tropical savannas of the Llanos with CORPOICA and the local universities.

TSBF Institute-Africa

NARS: Kenyatta University, Kenya, VLIR project on food security in Central Kenya; RF soybean project; JKUAT, Kenya, RF banana project; NARO, Uganda and LZARDI, Tanzania, DfID project on striga management in the Lake Victoria Basin; NARO, Uganda, RF project on exploring soybean potential in East Africa; KARI, Kenya, DfID project on striga management in the Lake Victoria Basin; University of Zimbabwe, Zimbabwe, NSF project on soil aggregation; Soil Research Institute, Ghana, NSF project on soil aggregation; INERA, D R Congo, ISAR, Rwanda, DGDC project on legume integration in systems in Central Africa; DGDC project on banana management in Central Africa; ISABU and IRAZ, Burundi, DGDC project on banana management in Central Africa; University of Kinshasa and University of Bukavu, D R Congo, VLIR project on cassava in D R Congo; Forest Dept of CIRAD, France, Kenyan Forestry Research Institute, Kenya, FOFIFA, Madagascar INCO DEV FOREAIM on Bridging restoration and multi-functionality in degraded forest landscape of Eastern Africa and Indian Ocean islands; INERA-DPF, Burkina Faso and Forest Dept of CIRAD, France, project CORAF/Gomme Arabique on Impact de l'inoculation par les rhizobiums sur la productivite de gommeraies plantees ou naturelles et la dynamique de facteurs lies au fonctionnement biologique des sols sous-jacents; INERA, Burkina Faso, ISRA, Senegal, FOFIFA, Madagascar, project ANR/MICROBES project on microbial observatories for the management of soil ecosystem services in the tropic; KEFRI, Kenya, Forest Dept of CIRAD, France and Grassland Research Station, Zimbabwe, project INCO DEV SAFSYS on Symbionts in agroforestry systems: what are the long-term impacts of inoculation of *Calliandra calothyrsus* and its intercrops; Antananarivo University, Madagascar and University of Makerere, Uganda project INCO DEV FOREAIM on Bridging restoration and multi-functionality in degraded forest landscape of Eastern Africa and Indian Ocean islands; University of Niamey, Niger and University Cheikh Anta Diop, Senegal, project CORAF/Gomme Arabique on Impact de l'inoculation par les rhizobiums sur la productivite de gommeraies plantees ou naturelles et la dynamique de facteurs lies au fonctionnement biologique des sols sous-jacents; Institut National de Recherches Agronomiques du Niger (INRAN); Niamey/Niger; Institut d'Economie Rurale (IER), Mali; ARS, Chilanga Zambia (Moses Mwale); EARO (Ethiopian Agricultural Research organization), Ethiopia; Ahmadu Bello University, Nigeria; ARI Mlingano, Tanzania; Egerton University, Kenya; University of Nairobi, Nairobi, Kenya (Rosemary

Atieno); Makerere University, Kampala, Uganda (Elizabeth K. Balirwa, Jonny Mugisha, John Baptiste, Mary Silver); Lake Basin Development Authority (Kenya) (Amos Ameya); Selian Agricultural Research Institute (Tanzania) (Sossi Kweka and Festo Ngulu); Southern Regions Research Institute, Ethiopia. IIAM, Mozambique project on Linking Farmers to Markets.

Advanced Research Institutes: J Six, University of California Davis, USA, NSF project on soil aggregation; R Merckx, Catholic University of Leuven, Belgium, VLIR project on food security in Central Kenya; E Tollens, Catholic University of Leuven, Belgium, DGDC project on legume integration in systems in Central Africa; R Swennen, Catholic University of Leuven, Belgium, DGDC project on banana management in Central Africa; S Recous, INRA, France, VLIR project on food security in Central Kenya; K Giller, WUR, Netherlands, EU project on AfricaNUANCES; L Brussaard, L Stroosnijder, WUR, Netherlands, WOTRO project on soil fauna and soil aggregation; Institut de Recherche pour le Developpement, France, project CORAF/Gomme Arabique on Impact de l'inoculation par les rhizobiums sur la productivite de gommeraies plantees ou naturelles et la dynamique de facteurs lies au fonctionnement biologique des sols sous-jacents; Institut de Recherche pour le Developpement, France, Centre of Ecology and Hydrology, UK' University of Norway, project INCO DEV FOREAIM on Bridging restoration and multi-functionality in degraded forest landscape of Eastern Africa and Indian Ocean islands; GSF-Munich, Germany and Institut de Recherche pour le Developpement, France project ANR/MICROBES project on microbial observatories for the management of soil ecosystem services in the tropic; Centre of Ecology and Hydrology and, Scottish Agricultural College UK, project INCO DEV SAFSYS on Symbionts in agroforestry systems: what are the long-term impacts of inoculation of *Calliandra calothyrsus* and its intercrops; BIOFORSK Soil, Water and Environment, Norway; JIRCAS (Japan International Research Center for Agricultural Sciences), Japan; Wye College, University of London (Colin Poulton); Kyoto University, Kyoto, Japan (Atsuyuki Asami); Ishikawa Prefectural University, Japan (Hiroshi Tsujii); University of Kiel, Kiel, Germany (Roll A.E. Mueller); Universite Catholique de Louvain (Eric F. Tollens); Swedish Univ. Agric. Sci (SLU), Uppsala, Sweden (Olof Andrén), University of Natural Resources and Applied Life Sciences (BOKU), Vienna Project on Linking Farmaers to Markets.

International Agricultural Research Centres: IITA, Uganda, RF project on ISFM for bananas; DGDC project on banana management in Central Africa; IITA, Nigeria (Alene Arega, David Chikoye, Robert Abaidoo); ICIPE and CIMMYT Kenya, DfID project on striga management in the Lake Victoria Basin; CIMMYT, Kenya, AATF project on striga management in Western Kenya; IFDC, Togo, WOTRO project on soil fauna and soil aggregation; INIBAP, Uganda, DGDC project on banana management in Central Africa; ICRAF, Kenya, RF project on soil fertility gradients and site-specific soil fertility management; ICRISAT, Niger; Centre d'Etude Régional pour l'Amélioration de l'Adaptation à la Sécheresse (CERAAS/ISRA); West African Rice Development Authority (Patrick M. Kormawa); African Highlands Initiative, Ethiopia.

International and Regional Agricultural Research Centers: CIMMYT, Kenya: Hugo de Groote, Mirjam Pulleman; CIP, Kenya: Charles Crissman; ICRAF, Kenya: Frank Place, Steve Franzel, Noordin Qureish, Bashir Jama, Richard Coe, Keith Shepherd; ICRISAT, Kenya: Ade Freeman; ICRISAT, Mali: Tabo; ICRISAT, Niger: Aboudoulaye, Abdoulaye and Mahamane; ICRISAT, Zimbabwe: John Dimes; IITA Ibadan, Nigeria- Abdou; IITA Uganda: Piet van Asten, Cliff Gold, Suleiman Okech; ILRI, Kenya: Patti Kristjanson, Steve Staal, Philip Thornton, Mario Herrero, Dannie Romney; ICIPE: Zia Khan; AATF: Mpoko Bokanga; West African Rice Development Authority – Patrick M. Kormawa; International Institute for Tropical Agriculture – Alene Arega, David Chikoye, Robert Abaidoo.

NGOs: FIPS, Kenya, RF project on soil fertility gradients and site-specific soil fertility management; SACRED-Africa, Kenya, RF soybean project; Diobass and Food for the Hungry, D R Congo, DGDC project on legume integration in systems in Central Africa; DGDC project on banana management in

Central Africa; UR2PI, Congo, ANR/MICROBES project on microbial observatories for the management of soil ecosystem services in the tropic; Hunger Project/Burkina Faso; Groupe d'Action pour le Développement Communautaire (GADEC) ; Tambacounda/Senegal; Union des Groupements Paysans de Mekhe (UGPM/Senegal); Projet Intrants/Niger; Groupement Nabonswendé de Tougouri/Burkina; Entente des Groupements Associés de Toubacouta (EGAT)/Senegal;Caritas-Kaolack/Senegal; AfriAfya (Caroline Nyamai-Kisia); CRS (Tom Remington); Farmers' Own Trading Company (Tony Margetts) Africa2000 Network, UEEF, Africare (Uganda).

The Private Sector: TSBF-Africa is also working with a wide array of prive sector and farmers associations. Some of those involved in Kenya as an example include:
Western Seed Company (Kenya)– Saleem Esmail; BIDCO OIL REFINERIES LIMITED (Kenya) – Dileswar Pradhan, Ashish Mandlik; Mukwano Group of Companies (Uganda) – Ibnul Hassan Rizvi; NUTRO MANUFACTURING EPZ LIMITED – Simon Glover; Ebubala Self-Help Group (Shianda Location of Butere Division, Kenya); Tushiauriane Self Help Group (Eluche Sub-location, Kenya); Nabongo Panga Self-Help Group (Matawa Sub-Location, Nabongo Location, Kenya); Jitolee Women Group (Lukohe sublocation, North Marama location, Butere Division, Kenya); Etako Women Group (Lukohe sublocation, North Marama location, Butere Division, Kenya); Bushe Women Group (Butere Division, Kenya); Shishebu farmers' Group (Shianda location, Butere Division, Kenya); Mabole farmers' field school (Shianda location, Butere Division, Kenya); Masaa Men and Women Group; Eluche Mwangaza Community Dev't Organization (Eluche Sublocation, Mumias Division, Kenya); Uriri farmers' cooperative society (Migori District, Kenya); Suna farmers' cooperative society (Migori District, Kenya) AMFRI farms (Uganda), Olivine Indutries, Harare, Reapers (Pvt) Ltd, Harare.

TSBF Institute-Latin America

ARIs: CIP, CIAT, IWMI, DIIS (Denmark), GTZ (Germany).

NARS: CORPOICA – La Libertad, Colombia; A. Rincón, R. Valencia, J.J. Rivera, C.J. Escobar; CORPOICA – Macagual, Colombia, C. Escobar; EMBRAPA – Soils, Brasil, H.Coutinho, C. Manzatto, A. de Andrade, A. Ármalo; EMBRAPA – Cerrados, Brasil, J.R. Correia; EMBRAPA – Agrobiologia, Brasil, A. Aquino; EMBRAPA – Cassava and Fruit Crops, A. Vilar Trindade; PROMIC (Bolivia); CEDEPAS (Peru); Dario Maya Botero Foundation (Colombia) CAR (Colombia); Regional Government, Moyobamba (Peru); The aqueduct company of Moyobamba EPSA (Peru); PROMACH (Ecuador); ECOPAR (Ecuador).

NGOs:
CENIPALMA, P.L. Gómez, F. Munevar.

Specialized Institutions: ETH, Zurich, Switzerland; Prof. E. Frossard, A. Oberson; Agricultural University of Norway, Norway; Prof. B.R. Singh; University of Gottingen, Germany, Prof. N. Claassen University of Freiburg; Prof. E. Wellmann; University of Chile; Prof. M. Pinto; University of Montana, USA, M.Rillig, D.; Cornell University, USA, J.Thies, M.Devare, J.Duxbury, L.Allee, J.Losey; University of California-Davis, USA, J.Six; Universidade Federal Rural de Rio de Janeiro, Brasil, R. Berbara; University of Western Australia, Australia, A. Conacher; Zhejiang University, China, W. Wu; University of Duke, U.S.A. Prof J. Reynolds; University of New Mexico, U.S.A, Jeff Herrick; Colegio de la Frontera Sur, México, Luis García Barrios; North Carololina State University, Jot Smyth.

International Agricultural Research Centers: CATIE, Costa Rica; J. Beer; ICRAF, R.Coe, K. Shepherd; IFDC, USA; D. Friesen; IWMI, Thailand, A. Noble; IRD, J.L. Janeau and C. Prat; FAO-Honduras, C.Paul, L.A. Welchez.

National Universities: Universidad Nacional de Colombia, M.Sánchez de Prager, Juan C. Menjivar, M. Prager, E. Madero; Universidad Nacional de Agricultura, Catacamas, Honduras, J. Reyes and W.Reyes; Escuela Nacional de Ciencias Forestales-ESNACIFOR, Honduras, P. Dubon, Z. Martínez; Centro Universitario Regional del Litoral Atlántico-CURLA, Honduras, Manuel López; Universidad Nacional Agraria de Nicaragua, M. Somarriba, I. Rodríguez, G. Bonilla; Universidad de los Andes (Colombia); Universidad Javeriana (Colombia); University of Florida (USA).

Private sector: CORPOMORTIÑO (Colombia), AGROALIZAL (Colombia), Ford Foundation

Others: FINAGRO (Fondo Nacional de Garantías Agropecuarias)

ANNEX-4: LIST OF PUBLICATIONS

TSBF Institute - Africa

Refereed journal articles

Journal articles published in 2005

Chianu, J., N. and Hiroshi, T. 2005. Integrated nutrient management in the farming systems of the savannas of northern Nigeria: what future? Outlook on Agriculture 34: 197-202.

Diouf D., Duponnois, R. Ba AT, Neyra, M. and Lesueur, D. 2005. Influence of rhizobial and mycorrhizal symbioses on growth and mineral nutrition of *Acacia auriculiformis* and *Acacia mangium* under salt stress conditions. Functional Plant Biology 32: 1143-1152.

Esilaba, A.O., Nyende, P., Nalukenge, G., Byalebeka, J., Delve, R.J. and Ssali, H. 2005. Resource flows and nutrient balances in smallholder farming systems in Mayuge District, Eastern Uganda. Agriculture, Ecosystems and Environment 109: 192-201.

Esilaba, A.O., Byalebeka, G., Delve, R.J., Okalebo, J.R., Ssenyange, D., Balule, M. and Ssali, H. 2005. On-farm testing of integrated nutrient management strategies in Eastern Uganda. Agricultural Systems 86: 144-165.

Lesueur, D. and Duponnois, R. 2005. Relations between rhizobial nodulation and root colonization of *Acacia crassicarpa* provenances by an arbuscular mycorrhizal fungus, *Glomus intraradices* Schenk and Smith or an ectomycorrhizal fungus, *Pisolithus tinctorius* Coker & Couch. Annals of Forest Sciences, 62: 467-474.

Mando, A., Ouattara, B., Sédogo, M., Stroosnijder, L., Ouattara, K., Brussaard, L., and Vanlauwe, B. 2005. long-term effect of tillage and manure application on soil organic fractions and crop performance under Sudano-Sahelian conditions. Soil & Tillage Reearch 80: 95-101.

Probert, M.E., Delve, R.J., Kimani, S.K. and Dimes, J.P. 2005 Modelling nitrogen mineralization from organic sources: representing quality aspects by varying C:N ratios of sub-pools. Soil Biology and Biochemistry 37: 279-287.

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Rondón, M. 2005. Reforesting the tropical savannas of Colombia: opportunities for carbon trading. Invited Oral presentation at the 3rd International Regional Meeting on Agroscience and technology. Villavicencio, Colombia. Nov 22-24, 2005.

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Rondón, M., White, D., Cajas, S. and Rincón, A. 2005. Proyectos MDL gestionados por Biocarbon Fund. Desafios y oportunidades. Experiencia de un proyecto pionero en Colombia. Poster presented at the International meeting on sustainable agriculture. Manizales, Colombia. July 20-22, 2005.

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ANNEX-5: LIST OF DONORS AND SPECIAL PROJECTS

ACIAR - Australia

- Extension to LWR2/1999/03, Integrated nutrient management in tropical cropping systems: improved capabilities in modeling and recommendations from ACIAR (awarded to TSBF-CIAT) (2003-2005).
- Integrated nutrient management in tropical cropping systems: improved capabilities in modeling and recommendations (2003-2005).

Austrian Government (BMF) - Austria

- Linking farmers to markets: Developing sustainable marketing systems to improve the competitiveness of small holder organic agriculture (2004-2006).

BMZ-GTZ - Germany

- Fighting drought and aluminum toxicity: Integrating functional genomics, phenotypic screening and participatory evaluation with farmers to develop stress resistant common bean and *Brachiaria* for the tropics (2005-2007).
- Bean genomics for improved drought tolerance in Central America (2003-2006).

Biocarbon Fund

- Rehabilitation of degraded lands through silvopastoral systems and reforestation of marginal lands in the Caribbean savannas of Colombia - Carbon trading (not research) project (2005-2007).

CIDA bilateral funds - Canada

- Using market-led approaches to drive investments in soil fertility management and improve production and incomes of rural communities in selected areas of the central watershed of Zimbabwe (2004-2005).
- Fuelling economic growth by increasing land productivity with grain legumes in Sub-Saharan Africa: Linking Technical options, technology transfer and market access to empower farmers (2003-2008).

CGIAR

- Payment for Environmental Services (PES) as a mechanism for promoting rural development in the upper watersheds of the tropics (CGIAR, WFCP, GTZ, CONDESAN and DIIS) (2006-2007).
- Achieving equitable and sustainable management of land and water in upper catchments: A proposal for linking regional soils consortia to Theme 2 of the CGIAR Challenge Program on Water and Food. SDC-Switzerland (2005-2007).

Challenge Program – Water and Food

- Enhancing rainwater and NUE in Volta (2005-2007).
- Quesungual Slash and Mulch Agroforestry Systems (QSMAS) (2004-2006).

Challenge Program – Generation

- Evaluation and development of transgenic drought-tolerant varieties. Commissioned research Project (2005-2006).

CRC - Colombia

- Ubicación y Medidas de Control de Procesos Erosivos de la Cuenca del Río Cauca (2005).

CTA

- Training workshop on FPR&SU (2005).

CVS - Colombia

- Environmental impact of reforestation (2005).

DGDC - Belgium

- Enhancing the resilience of agro-ecosystems in Central Africa: a strategy to revitalize agriculture through the integration of natural resource management coupled to resilient germplasm and marketing approaches (2005-2007).
- Building impact pathways for improving livelihoods in *Musa*-based systems in Central Africa (2005-2007).
- Legumes, markets, and nutrition (2005-2007).
- Bananas (with INIBAP) (2005-2007).

DFID - England

- Striga, stemborer, soil fertilty management (2005).
- Linking demand for, and supply of, agricultural production and post-harvest information in Uganda. (200-2005).
- Integrated pest and soil management to combat *Striga*, stemborers and declining soil fertility in the Lake Victoria basin (via ICIPE) (2003-2006).

DGIS – The Netherlands

- Improving cassava drought tolerance through enhanced mycorrhizal simbiosis (Cassava Biotechnology Network-LAC Small Grants DGIS) (2005).

European Union

- FAO-CIAT project on seed production systems (2004-2006).

GEF - UNEP

- Conservation and sustainable management of below ground biodiversity, Phase I (via UNEP). (2002-2007).
- Desert Margins Programme (DMP) Phase I (2003-2008).
- PDF-B: Overcoming land degradation to mitigate deforestation in the humid tropics (2006).

IFAD

- Combating soil fertility decline to implement smallholder agricultural intensification in sub-Saharan Africa (2004-2005).

IDRC - Canada

- Strengthening Folk Ecology (2005-2007).
- Building teamwork and research capacity for sustainable agricultural development in the dry lands of Africa: The challenge of combining water and nutrients (2004-2006).
- Combining rainwater and nutrient management strategies to increase crop production and prevent soil degradation in the Desert Margins of West Africa (2004-2006).
- Strengthening Folk Ecology: Applying community-based learning and communication strategies to improve soil fertility and livelihoods in Western Kenya (2005-2008).

JIRCAS - Japan
- Nitrification Inhibition (2004-2006).

Kellogg Foundation
- Institutional Strengthening of CAIS - an alliance for local codevelopment (2005-2007).

National Science Foundation - USA
- Social dynamics of integrated production systems for food insecure households in marginal environments of sub-Saharan Africa. (2005-2008).
- The interaction between resource quality and aggregate turnover controls ecosystem nitrogen and carbon cycling. (2004-2006).

Norway Government
- Linking policy and natural resource management to combat food insecurity poverty and land degradation in the Ethiopian highlands (2004-2007).

OPEC (Fund for International Development)
- Increasing legume efficiency (2005).
- Increasing efficiency of legume cover crops' (LCCs) use in selected benchmark sites of Africa (2003-2005).

Rockefeller Foundation
- Banana (2005).
- Promiscuous soybean processing and utilization for improving the health and nutrition of rural households in HIV/AIDS affected areas of Kenya and Uganda (2005-2006).
- Soybean (2005-2006).
- Legume network for Uganda-prop devt. (2002-2005).
- ISFM in the tropics (2005-2007).
- Book Publishing (Yaoundé proceedings (2005).
- Valuing within-farm soil fertility gradients to enhance agricultural production and environmental service functions in smallholder farms in East Africa (2004-2006).
- Integrated Soil Productivity Initiative through Research and Education (INSPIRE) Phase Two: Scaling-up and out INSPIRE (awarded to TSBF-CIAT) (2003-2005).
- Publishing the proceedings of the African Network for Soil Biology and Fertility Network (AfNet) International Symposium held in Yaoundé, Cameroon May 17-21, 2004 (2004-2005).
- Exploring the multiple potentials of soybeans in enhancing rural livelihoods and small industry in East Africa (2004-2007).
- Exploration of integrated soil fertility management for banana production and marketing in Uganda and Kenya: Arbuscular Mycorrhizal Fungi help establishment and production of tissue culture banana (2005-2006).

SANREM - CRSP - USA
- Agro-pastoral transitions (2005).

SDC-ZIL - Switzerland
- Adaptation of *Brachiaria* grasses to low-P soils (2003-2006).

USAID

- Congo livelihood improvement and food security (2004-2006).
- Linkages Fund: Black carbon interactions with soil functions (2004-2005).
- Assessing the effect of Bt crops and insecticides on arbuscular mycorrhizal fungi and plant residue carbon and turnover (USAID, Soil Management CRSP) (2003-2008).

VLIR (Flemish Inter-University Council)

- Integrated soil fertility management strategies to enhance food security in the Central Highlands of Kenya (2003-2007).

WECARD

- Water harvesting (2005-2007).
- Fertilizer Micro dosing (2005-2007).
- Promoting Indigenous PR (2005-2007).